

## Valley County Planning and Zoning

PO Box 1350 • 219 North Main Street  
Cascade, ID 83611-1350



Phone: 208-382-7115  
Fax: 208-382-7119  
Email: [cherrick@co.valley.id.us](mailto:cherrick@co.valley.id.us)

**STAFF REPORT:** C.U.P. 21-45 RedRidge Preserve Subdivision - Preliminary Plat  
**HEARING DATE:** February 10, 2022 (Continuation of Public Hearing on Jan. 13, 2022)  
**TO:** Planning and Zoning Commission  
**STAFF:** Cynda Herrick, AICP, CFM  
Planning and Zoning Director  
**APPLICANT / OWNER:** The McCall Associates LLC  
P.O. Box 10117  
Boise, ID 83707  
**AGENT:** Brian Dickens  
Blackhawk Manager, LLC  
PO Box 10117  
Boise, ID 83707  
**ENGINEER:** RiveRidge Engineering CO  
2447 S Vista Ave  
Boise, ID 83705  
**SURVEYOR:** Secesh Engineering  
P.O. Box 70  
McCall, ID 83638  
**LOCATION:** RP17N02E021535, RP17N02E030006, RP17N02E100006,  
RP17N02E110605, RP18N02E269005, RP18N02E340006,  
RP18N02E350006, RP18N02E363520  
Sections 2, 3, 10, and 11, T.17N, R.2E and Sections 26, 34, 35, and  
36, T.18N, R.2E, Boise Meridian, Valley County, Idaho  
**SIZE:** 1,614 acres  
**REQUEST:** Single-Family Residential Subdivision  
**EXISTING LAND USE:** Agricultural – Productive Timberlands

Planning and Zoning Commission continued the public hearing to February 10, 2022. The Commissioners desired more information and clarification from the Applicant.

Well logs and groundwater resource evaluation for individual well were part of the original application previously submitted to you. Included in this packet will be the Preliminary Geotechnical Engineering Services report.

### 1. ADDITIONAL QUESTIONS SENT TO APPLICANT – including P&Z Questions:

- 1) Clarify pertinent attributes of the subdivision as it is being presented currently.

- 2) Letters from conversations with agencies, CDH, DEQ and/or IDWR.
- 3) Soil type data.
- 4) Concerned with septic and drainfields when sewer is so close. Sewer was not in application but presented at the public hearing. Should they be compelled to connect to sewer since it is close? Recommend a hybrid and put smaller lots in first 3 phases on sewer.
- 5) Has a shared road agreement been met with Blackhawk 5?
- 6) How much of the construction on the previously approved Phase 1 has been completed?
- 7) Has a new or updated Wildfire Mitigation Plan been completed or submitted to P&Z?
- 8) Have any of the CDH requirements for test holes, groundwater monitoring, etc been started or completed or will this all be done as a condition of approval or a condition prior to recordation of the final plat?
- 9) Timing of phasing seems incredibly long for infrastructure traffic impacts on neighboring properties. Could this be shortened and extended as needed?
- 10) What level of bonding or financial assurance is expected?
- 11) What impact does being in a Herd district have on the property specifically as it relates to CC&R's related to fencing?
- 12) It sounds as though IDWR does not believe the aquifer would be negatively impacted with the addition of 135 additional private wells but can you further discuss the assessments that have been done to come to this conclusion?
- 13) Please discuss plans to preserve water quality that could impact Duffner Creek, Blackhawk Lake and the Payette River.
- 14) Is wetland delineation required?
- 15) Please further explain animal habitat considerations.
- 16) Would the development impact natural drainage throughout the area and if so please explain how this will be addressed?
- 17) Has any environmental impact study been completed? What has been done? A concern identified by neighbors.
- 18) Have the Valley County Engineers responded to the correct drawing set of preliminary site grading and drainage plans?
- 19) A fact sheet addressing which lots would be central sewer and water, and which would be septic
- 20) Address ID Fish and Game letter and how the applicant will comply, including CCRs
- 21) Address traffic impacts
- 22) DEQ and IDWR conversations and requirements
- 23) Water quality concerns
- 24) Central District Health requirements
- 25) More concise picture of application
- 26) Internal roads and previously approved variance for narrow roads
- 27) Some analysis on soil types since water drains toward the river

**2. Responses from the Applicant since the public hearing OR presented as an exhibit at the January 10 public hearing:**

- **Summarized response to the Commissioner's questions for clarification - dated**
- **Exhibit 6 at January 10<sup>TH</sup> public hearing – Letter dated January 10, 2022:**
  - General Statements
  - Fire Mitigation Plan
  - Landscape Plans/Submittals/Enforcement
  - Water
  - Septic
  - Road Department Response
  - Responses to Fire Departments
  - Confirmed easements on Plat
  - IDEQ Response
  - Valley Soil and Water Conservation Response
  - Idaho Fish and Game Response
  - Response to Neighbors
  - Valley County Code Comments – Comprehensive Plan and Grading
  - Response to the Staff Questions in Staff Report
  - Response to the Staff Proposed Conditions of Approval
- **Short Summary of Project from email dated January 14, 2022:**
  - 135 lots, average 6 acres
  - No central sewer or water
  - Fire suppression through extension of WMSW hydrants
  - Soil summary
  - CDH records on the 50 lots already approved for septic
  - County Engineer will approve all site grading storm water management upon approval.
- **Additional submittal in email on January 31, 2022:**
  - Email with Gary Carrol, DEQ, confirming WMSW, Inc. is in good standing and that there will be no central sewer or water with this project at this time.
  - Water Quality Discussion in email dated January 31
  - Herd District Map
  - Water Quality and the Grazing Animal from University of Nebraska
  - Livestock Grazing Effects on Phosphorus Cycling in Watersheds
  - Monitoring runoff from cattle-grazed pastures for a phosphorus loss quantification tool – University of Nebraska
  - Livestock Manure and the Impacts on Soil Health: A Review – MDPI
  - Implementation of BMP Strategies for Adaptation to Climate Change and Land Use Change in a Pasture-Dominated Watershed
  - Conservation practice effectiveness and adoption: unintended consequences and implications for sustainable phosphorus management

### 3. Additional Comments received since the public hearing on January 13, 2022.

#### Agency comment received:

Valley County Soil and Water District submitted information on septic system maintenance. (January 2022)

#### Neighbor comment received:

##### Abbreviations

DEQ (*Idaho Department of Environmental Quality*)

PRS#2 (*Payette River Subdivision No. 2*)

BOTR (*Blackhawk on the River*)

WMWS (*West Mountain Water and Sewer*)

Chris Sours, Vice President, PRS#2 Property Owner's Association, was surprised to hear of the intent to utilize the WMWS system for 50 or more lots within the proposal. Where is the data supporting that the system could handle up to 400 lots? WMWS was initially designed, sized, and constructed to accommodate Payette River Subdivision No. 2 and BOTR subdivisions. DEQ Permit M-17-03 states that detailed plans and specifications shall be submitted to the DEQ for review and approval prior to construction, modification, or expansion. C.U.P. 21-45 approval should be denied until DEQ completes a review. Additionally, expansion costs shall be covered by the developer and not the existing users of WMWS. (Jan. 24, 2022)

Judy Secrist, property owner in PRS#2, is concerned about the intent to use WMWS for an additional 50 or more sewer hook-ups. WMWS was designed to serve PRS#2 and BOTR. Initial construction and ongoing expenses costs were passed thru to property owners. At this time, the two subdivisions are getting close to being fully built out, thus closely reaching the limits of the WMWS design. Cost of expanding the current facility is estimated to be in the millions. Any cost of expanding and maintain an expanded sewer system should be the sole responsibility of the developer. The proposal should be denied until full review and approval of the proposed expansion is completed by DEQ. (Jan. 24, 2022)

Jennifer and Joe Riso, 275 Brook Drive in PRS#2, are concerned about the expansion capabilities of WMWS and associated costs. The proposal should be denied until full review and approval of the proposed expansion completed by DEQ. (Jan. 24, 2022)

Terry Avitable, 119 Moon Drive in PRS#2, is concerned; WMWS cannot possibly take on more affluent. (Jan. 24, 2022)

A. Bruce Cleveland and Roberta L. Cleveland, owners of PRS#2 Lots 13 and 14, support Mr. Sours letter requesting denial until a full review of expansion is completed by DEQ. Any expansion costs should be covered by the developer McCall Associates LLC. (Jan. 24, 2022)

Tim and Nadeane Rutledge, owners of PRS#2 Lots 30 and 31, stated that any expansion to WMWS be at the cost of the developer. (Jan. 25, 2022)

Chris and Jack Oberti, BOTR property owner, request denial. Any future development of RedRidge Preserve needs to have environmental studies pertaining to the geology of the terrain for septic tanks, wells, erosion, and the aquifer. The DEQ Reuse Permit M-117-03 allows WMSW to accommodate 124 EDU hook-ups. The current plant, a Class C recycled water reuse



facility, is presently authorized to treat the 124 hooks. The users of the permit are Blackhawk on the River and Payette Estates subdivision. Mr. Dicken has indicated in his correspondence he only intended to keep the "existing 124 EDU's". (Jan. 26, 2022)

Pat and Richard Bicknell, Moonridge Drive in Payette River Subdivision, is requesting denial until a full review and approval of the proposed expansion is completed by DEQ. WMWS is at capacity. (Jan. 26, 2022)

Michael and Sheila Forrest, 150 Current Drive in PRS#2, stated that they have protections from anything WMWS wishes to do as it is a privately-owned system. As part of the C.U.P. approval, Valley County required connections to WMWS for sewage disposal. Therefore, Valley County has a fiduciary responsibility to make sure the existing rate payers are not taken advantage of by WMWS with large rate increases. The development costs of the property alone given current construction costs coupled with the cost of WMWS expansion will make the lots quite expensive. It that good progress for our area or will it be just another example of the land in Valley County being available to only the very wealthy? (Jan. 27, 2022)

Curt and Kim Meske, 45 Shooting Star Lane in BOTR, are opposed due to: risk to fisheries and water quality at Hait Reservoir (aka Blackhawk Lake); lack of capacity for WMSW; and unlikelyhood of applicant following thru with conditions and stipulations. (Jan. 27, 2022)

Linda Morris, on behalf of 45 BOTR property owners, is opposed. She would like greater notice. They are appreciative of the commissioners who noted the discrepancy between the submitted application and the statements made by Mr. Dickens during the public hearing on January 13, 2022. Integrating a new subdivision into WMWS would have a tremendous impact on the two subdivisions it presently serves: the 144-lot BOTR and 88-lot PRS#2. Mr. Dickens stated that the proposed water and sewer infrastructure could cross BOTR common areas; however, all common areas were deeded to BOTR in October 2020. Mr. Muroff's involvement is a concern. They would like more information on the expired DEQ permit and WMWS capacity. Connecting 50 or more units to WMWS will have a direct impact on BOTR owners. The PZ Commissioners should deny C.U.P. 21-45 until the listed issues are addressed and ownership status of WMWS is determined following the MAY 2022 auction; and address the infrastructure costs and DEQ engineering requirements to meet the current water and sewer standards for the existing 232 owners in BOTR and PRS#2. (Jan. 28, 2022)

Darcy and Travis Reese, 361 Moon DR, are full-time residents in PRS#2. They are opposed. The sewer system regulations need greater attention. The current DEQ permit expired in 2020. The cost of expansion should be paid by McCall Associates LLC. (Jan. 28, 2022)

Kelly Guy, 22 Arrowgrass Way in BOTR, is opposed. The changes to water and sewer as suggested by the developer in the January 13, 2022, hearing should trigger a new notification period as they are material changes to the original permit application. The WMSW facility is operating under a expired permit from DEQ. There is a discrepancy between the maximum of 124 EDU's on the expired permit and the developer's statement that the facility is permitted for 250 homes and designed for 450. Traffic and road maintenance on West Mountain Road is a concern. Page 37 of the application refers to perimeter fencing. More information is needed as any fencing could create problems for the wildlife and should be limited in scope. (Jan. 28, 2022)

Walt Sledzieski, Blackhawk Lake Estates, is opposed as he states that this application is a ploy to inflate the perceived value of this property and other assets that will be auction off in the spring. (Feb. 2, 2022)

Daniel R Barnes, 295 Brook Drive in PRS#2, is opposed. A full review of WMWS must be completed by DEQ. (Feb. 2, 2022)

**STAFF COMMENTS / QUESTIONS FROM STAFF REPORT FOR JAN. 13, 2022:**

(New Question)

1. Clarify if the right-of-way of the private roads will be 70' wide with decreased driving surface.

(Previous Questions – already answered on January 10, 2022)

1. A note limiting each lot to one wood-burning device should be added to the plat. Will CCR's address fertilizers, fire resistant building materials, firewise landscaping, maintenance and continued implementation of the Wildfire Mitigation Plan, building envelopes, etc.? Recommend the CCR's also address long-term maintenance of septic systems.
2. Describe plan to implement Wildfire Mitigation Plan. Will you implement on a phase-by-phase basis prior to recordation of each final plat or in its entirety?
3. Will CCR's have a setback from the Blackhawk Lake Subdivision?
4. Will you delineate the wetlands or do building envelopes?
5. All easements must be shown on the plat. See the 2009 letter from John Russell.
6. The variance of road surface width will need to be approved by the Valley County Engineer, fire department, and Board of County Commissioners.
7. Are streetlights proposed?
8. All road names shall be approved by the Valley County Planning and Zoning prior to final plat approval. Some of the road names shown on the maps are not acceptable. A legible map with proposed road names is needed for approval.
9. The approval period should not be open-ended. What should the maximum time period between phases be without requiring an extension request? When should the entire project be finalized or require an extension? Ten phases at two years each; therefore, completion by December 31, 2042?
10. The original application in 2007 proposed conservation easements on large portions of the property. Will you have any conservation easements?
11. The original application proposed three different extraction sites for gravel and roadmix. Do you plan on using these sites or do you want to apply for a different conditional use permit for gravel extraction? Typically, gravel can be mined onsite for internal roads without a conditional use permit.
12. Does any portion of this proposal contain groomed snowmobile trails or the original Redridge RD? If so, will you provide easements for continued public use?
13. Idaho Fish and Game Department submitted a lengthy response. Please address all matters such as fencing, domestic animals, garbage cans, etc. Will these items be added to the CCR's?

## **ATTACHMENTS:**

- Conditions of Approval
- PZ Commission Minutes of Jan. 13, 2022
- Additional Questions
- Applicant's Response to Additional Questions
- Responses received after January 13, 2022
- Septic System Information (Education Materials from Lillehaug)
- Preliminary Geotechnical Engineering Services report

## **Conditions of Approval**

1. The application, the staff report, and the provisions of the Land Use and Development Ordinance are all made a part of this permit as if written in full herein.
2. Any change in the nature or scope of land use activities shall require an additional Conditional Use Permit.
3. The use must be established according to the phasing plan, or the conditional use permit will be null and void. All final plats shall be recorded by December 31, 2042.
4. The issuance of this permit and these conditions will not relieve the applicant from complying with applicable County, State, or Federal laws or regulations or be construed as permission to operate in violation of any statute or regulations. Violation of these laws, regulations or rules may be grounds for revocation of the Conditional Use Permit or grounds for suspension of the Conditional Use Permit.
5. Must have an approved storm water management plan and site grading plan approved by the Valley County Engineer prior to any work being done on-site and prior to recordation of a plat.
6. A wetland delineation is required, or the wetland areas must be identified on the plat as no-build areas.
7. Must bury conduit for fiber optics within roadways.
8. Must record Articles of Incorporation and create a Homeowner's Association prior to recordation of a final plat.
9. A Declaration of Installation of Utilities shall be placed on the face of the plat if all utilities are not in place at the time of recordation.
10. Must comply with the requirements of the McCall Fire District and Donnelly Rural Fire District. A letter of approval is required from both districts if not annexed into the McCall Fire District.
11. All easements must be shown on final plats.
12. All lighting must comply with the Valley County Lighting Ordinance.
13. CCR's should address lighting, noxious weed eradication, fertilizer use, continued maintenance with the Wildfire Mitigation Plan, firewise landscaping, fire resistant materials,

education on long-term maintenance of septic systems, and limit each lot to one wood burning device. Wildlife-friendly fencing is recommended.

14. Shall place addressing numbers at the residence and at the driveway entrance if the house numbers are not visible from the road.
15. A floodplain note should be added to the plat.
16. Financial guarantees or certificates of completion shall be in place prior to recordation of plats.
17. Prior to construction of any on-site improvements, the applicant shall meet with the Valley County Road Director and/or Board of County Commissioners to discuss off-site road improvements. If an agreement cannot be reached the application shall be set for another public hearing with the Valley County Planning and Zoning Commission to determine if the application can be approved without improvements and still meet their mandates concerning public health, safety, and welfare matters. The discussion will be concerning current road conditions and potential mitigation for impacts caused by the development.
18. The following note shall be placed in the notes on the face of the final plat:  
    "The Valley County Board of Commissioners have the sole discretion to set the level of service for any public road; the level of service can be changed."

#### **END OF STAFF REPORT**

# Valley County Planning and Zoning Commission

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Phone: 208-382-7115  
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Neal Thompson, Chairman  
Ken Roberts, Vice-Chair

Brian Benton, Commissioner  
Katlin Caldwell, Commissioner  
Scott Freeman, Commissioner

## MINUTES

Valley County Planning and Zoning Commission  
January 13, 2022  
Valley County Court House - Cascade, Idaho  
PUBLIC HEARING - 6:00 p.m.

**A. OPEN:** Meeting called to order at 6:05 p.m. by Acting Chairman Thompson. A quorum exists.

PZ Director – Cynda Herrick:	Present
PZ Commissioner – Katlin Caldwell	Excused
PZ Commissioner – Sasha Childs:	Present
PZ Commissioner – Scott Freeman:	Present
PZ Commissioner – Ken Roberts:	Present
PZ Commissioner – Neal Thompson:	Present
PZ Assistant Planner – Lori Hunter:	Present

**B. MINUTES:** Commissioner Roberts moved to approve the minutes of December 9, 2021, and December 16, 2021. Commissioner Childs seconded the motion. Motion carried unanimously.

**C. NEW BUSINESS:**

- 1. C.U.P. 21-42 Dame Multiple Residence:** Taylor Dame is requesting a conditional use permit for two residences on one parcel. A 1188-sqft home is on the property. He would like to add a garage with 1200 sqft of living space. The homes would share a driveway and an individual well. Northlake Recreational Sewer and Water District would provide sewer. The property is addressed at 2147 Lydia Drive. The 0.6-acre parcel is Royal Scot Subdivision No. 6, Lot 21, located in the SE ¼ Section 32, T.16N, R.3E, Boise Meridian, Valley County, Idaho. Action Item.

Acting Chairman Thompson introduced the item and opened the public hearing. The applicant is not present, and Director Herrick was unable to contact him on the phone. Acting Chairman Thompson continued the public hearing until later tonight.

- 2. C.U.P. 21-43 Huckleberry Ridge Subdivision – Preliminary Plat:** Sal Gallucci is requesting a conditional use permit for a 9-lot single-family subdivision on 40 acres. Lots would be accessed from a new private road onto West Mountain Road (public). A variance for a cul-de-sac greater than 900-ft is requested. Proposed lot sizes range from 2.68 acres to 7.37 acres. Individual wells, individual septic systems, and shared driveways are proposed. The site includes parcels RP17N02E230004 and RP17N02E230065 in the NE ¼ Section 23, T.17N, R.2E, Boise Meridian, Valley County, Idaho. Action Item.

Acting Chairman Thompson introduced the item and opened the public hearing. Acting Chairman Thompson asked if there was any *ex parte* contact or conflict of interest. There was none.



5. **C.U.P. 21-45 RedRidge Preserve – Preliminary Plat:** The McCall Associates LLC is requesting a conditional use permit for a 135-lot single-family subdivision in ten phases. Proposed lot sizes range from 3 acres to 17 acres. Individual wells and individual septic systems are proposed. Access would be provided from two locations on West Mountain Road onto private roads. A variance to the private road width is requested. The site includes approximately 1,614 acres in Sections 2, 3, 10, and 11, T.17N, R.2E and Sections 26, 34, 35, and 36, T.18N, R.2E, Boise Meridian, Valley County, Idaho. Action Item.

Acting Chairman Thompson introduced the item and opened the public hearing. Acting Chairman Thompson asked if there was any *ex parte* contact or conflict of interest. There was none.

Ken Roberts noted that he was a PZ Commissioner when the some of the original Blackhawk subdivisions were discussed and approved. He does not believe this impacts his ability to make an impartial decision on C.U.P. 21-45.

Acting Chairman Thompson asked for the staff report. Director Herrick presented the report and summarized the following exhibits:

**Exhibit 1** – Pete Fitzsimmons, 8 Sawtooth CT, is opposed. Reasons include deleterious effect of water quality, fire risk, effect on neighboring infrastructure, effect on property values, and concerns with McCall Associates. (Jan. 6, 2022)

**Exhibit 2** – Paul Ashton, Parametrix and Valley County Engineer, stated this project will require review and approval by Valley County of the site grading and drainage plans, drainage calculations, erosion control measures and best management practices prior to final plat approval. A complete set of site grading and preliminary plat documents must be resubmitted. A variance may be warranted based on our initial review, but further analysis will be completed when plans are resubmitted. (Jan. 12, 2022)

**Exhibit 3** – Sima Muroff, representing the applicant, replied to comments of Valley County Engineer (Jan. 11, 2022)

**Exhibit 4** – Garrett de Jong's, McCall Fire Chief, email chain regarding requirements. Fire hydrants may be spaced out based on parcels and general locations of structures, instead of the 600-ft maximum distance between hydrants. (Jan. 10, 2022, and Jan. 11, 2022)

**Exhibit 5** – Blackhawk Manager, LLC, representing the applicant, formally requested approval of a variance to reduce the 28-ft gravel private roadway width to a proposed 24-ft roadway width that will consist of 20-ft of paved surface and 2-ft gravel shoulders. (Jan. 11, 2022)

**Exhibit 6** – Blackhawk Manager, LLC, representing the applicant, replied to the staff report and added information regarding the application. (Jan. 10, 2022)

**Exhibit 7** – Geoffrey Wardle of Clark Wardle represents Blackhawk Lake Estates Subdivision Phase 5 property owners. When Blackhawk 5 was platted, it was contemplated that other developments in the area would connect to the private roads within Blackhawk 5. He requests that the applicant be required to enter into a reciprocal road maintenance and easement agreement with the Blackhawk 5 property owners and the Blackhawk Lake Estates HOA. (Jan. 7, 2022)

**Exhibit 8** – Brian Dickens, West Mountain Sewer and Water supports the proposal and will allow RedRidge Preserve to access our fire hydrants and extend the line throughout their proposed community to satisfy their fire suppression needs. To the extent the owners of the RedRidge development are willing to invest in these improvements, we would be thrilled to provide sewer, waste-water treatment, reclaimed water, and potentially potable water service. (Jan. 10, 2022)



- Exhibit 9** – Blackhawk Lake Estates Board of Directors are opposed to the proposal. Water and environmental concerns should be addressed before making any decision on whether to approve the addition of 135 new homesites on land bordering our community. If not limited in scope and responsibly managed, this development would pose a serious risk of adversely impacting Blackhawk Lake, its ecosystem, and the Blackhawk Lake Estate homeowners' use and enjoyment of the lake. Concerns include water quality; water table level; lake water level and drainage. The application calls for altering, diverting, and/or impounding upstream water or using water for reasons such as irrigation that may result in diminished water volume flow into the lake; the Commission should require a drainage and development plan that will not result in any reduction of flow, including in Duffner Creek. (Jan. 9, 2022)
- Exhibit 10** – Lori Gibson Banducci, 3464 West Mountain Road, states that West Mountain Road safety and durability needs improved. A paved bike path, parallel to the current road, would ensure that this road continues to be a viable biking road. (Jan. 7, 2022)
- Exhibit 11** – Karen and Steve Clautice, 10 Minidoka Court, are concerned about West Mountain Road conditions. The road is used in all weather by joggers, dog walkers, and in snow-free months by many bicycles. In the last year, increased speed limits and increases in both heavy commercial traffic and residential traffic have made West Mountain Road unsafe. The road needs to be rerouted or re-engineered from the junction with Deinhard Lane. The roads need wide, smooth, paved shoulders for bicyclists and pedestrians. (Jan. 10, 2022)
- Exhibit 12** – Mike and Laurie Josepher, Blackhawk Lake homeowner, is opposed and are concerned about the effect on water quality upstream from the Duffner Creek inlet into Blackhawk Lake as well as potential pollutants such as fertilizer, chemicals, and sewage that may get washed into the lake. The homesites would also tap into the same aquifer as their personal well. (Jan. 9, 2022)
- 
- Exhibit 13** – Ron and Dino Tarro homeowners at Blackhawk Lake, support the analysis and requests in the Blackhawk Association's letter [Exhibit 9]. (Jan. 10, 2022)
- Exhibit 14** – Tom and Angie Hannigan, 175 Stillwater Court, Blackhawk Lake Estates, are opposed. Concerns include reduction or contamination of the water supply. A septic plan should be completed prior to approval. They agree with the concerns stated in the Blackhawk Association's letter [Exhibit 9]. (Jan. 11, 2022)
- Exhibit 15** – Chris and Jack Oberti, 25 Fawnlilly in Blackhawk on the River, ask that the request be denied until certain issues are resolved. Prior to approval, environmental studies on geology, septic systems, runoff and erosion, and the ability of the underlying aquifer to sustain water levels and wells should be required. A traffic study is needed to anticipate additional road usage. What entity will be responsible for emergency calls to the subdivision (fire and law enforcement)? Things have changed since the original CUP and this development should be a "stand-alone" development with no reciprocity or use to the existing developments of Blackhawk on the River, Blackhawk Ranch, or Blackhawk Lake. (Jan. 11, 2022)
- Exhibit 16** – Mike and Bronny Bowman, Blackhawk Lake Estates landowners, fully support the comments of the Blackhawk Lake HOA [Exhibit 9]. (Jan. 11, 2022)
- Exhibit 17** – Mary Horkan, a member of the Blackhawk Lake Estates POA Board, is opposed due to water and environmental concerns. She is also concerned about the impact this development would have on McCall's and Valley County's challenged infrastructure and depleted workforce. (Jan. 12, 2022)

Director Herrick displayed the GIS map of the proposed site and surrounding area on the projector screen. West Mountain Road is a 100-ft right-of-way. The area served by West Mountain Sewer and Water was reviewed.

Acting Chairman Thompson asked for the applicant's presentation.

Brian Dickens, Meridian, Idaho, is the independent manager and Chief Executive Officer of McCall Associates, Blackhawk Gold, Blackhawk on the River LLC, and West Mountain Sewer and Water. He believes the Commissioners' time tonight would be best spent addressing their specific questions. He provided background to his involvement. On June 1, 2017, Mr. Dickens was appointed Independent Manager for McCall Associates by a federal court order. His experience and role as a developer consists of 4-5 years in this particular project. He is requesting basically a reinstatement of the prior approval with minor changes. He is required to manage the company in the best interest of investors. Until the fines are paid on the case that resulted in Mr. Dickens' appointment, Sima Muroff is suspended from participating in any managerial capacity even though he remains a 20% owner of the projects. The federal court order and settlement allows Mr. Dickens to employ or compel Mr. Muroff's cooperation whenever needed in the best interest of the investors. Therefore, Mr. Muroff has been conscripted to provide unpaid consulting services and is available to answer Commissioner's questions, particularly regarding the previous application.

Mr. Dickens is the sole full-time employee of McCall Associates. He employs attorneys, accountants, surveyors, engineers, etc., on a contractual basis.

Mr. Dickens replied to questions from the Commissioners. The current proposal wraps around Blackhawk Lake area. The two access points were discussed. McCall Associates also own adjacent property that also has access to West Mountain Road near Smylie Lane via the FAA Road for future access. DF Development owns property to the west prior to the Valley County / Adams County line. McCall Associates also owns a small triangle of property in Adams County.

Central sewer and water system is not appropriate for much of the property owned by McCall Associates. Well and septic system preliminary approval has been obtained for 50 lots.

Fire hydrants would be located throughout the entire development. A community well and storage tanks would provide water for those areas that the water lines from West Mountain Sewer and Water cannot reach.

The applicant has previously monitored and determined septic sites. The existing and proposed area serviced by West Mountain Sewer and Water was discussed; currently services are available to the southernmost portion of Blackhawk on the River. Centralizing water in the Duffner Creek area would mitigate impacts to the creek. Currently 250 homes are serviced; the system is designed for 450+ if it is upgraded to Class A water with improvements. The system is currently Class C water; this is for fire hydrants. There are currently 88 customers but also 68 sold lots that have not yet been built on in the Blackhawk on the River subdivisions.

Accesses to the property from West Mountain Road were discussed. The topography of the site was discussed. A paved road is superior to a dirt/gravel road. It is not practical at this site to have a 24-ft paved road as required by the private road standards. Therefore, the applicant is requesting a variance to the private road standards due to topography.

Part of the conditions and agreements with the original approval included money for paving and land given for right-of-way off West Mountain Road from Wisdom Road up to the Blackhawk gate. Maintenance of West Mountain Road was discussed. Director Herrick stated that if impact

fees are approved, they would take affect at time of building permit(s). Property taxes and levies for road maintenance were discussed. Condition of approval # 17 forces the applicant to talk to Road Department Director and/or Board of County Commissioners.

The PZ Commissioners requested the applicant to address comments from Fire Districts and other response letters.

Mr. Dickens referred to maps and preliminary plat within the application and presented the following large exhibits.

**Exhibit 18** – Redridge Property Master Plan map show the original plan that is not realistic today with his fiduciary requirements. The proposal today does not include a golf course or boutique hotel. C.U.P. 21-45 application is for 135 single-family-residential lots with septic and wells. Part of the property may be able to obtain sewer and water but that is not determined at this time.

**Exhibit 19** – Map of preliminary plat with topography

**Exhibit 20** – Map of preliminary plat, topography, and road grade.

**Exhibit 21** – Large prints of the preliminary plat, topography, and road grade information.

Acting Chairman Thompson asked for proponents. There were none.

Acting Chairman Thompson asked for undecided.

Harry Soulen, Soulen Livestock Company, Weiser, ID, is not opposed to the project. Soulen Livestock does own property south, east, and west of this project. Soulen Livestock has sheep grazing, timber, and gravel businesses on their adjacent property. He would like reassurance that the movement of the sheep and trucks will not be obstructed by future lot owners. He wants the development's CCRs to fully disclose information about the existing livestock, timber, and gravel activities.

John Lillehaug, McCall, is a Valley County Soil & Water District board member. He would like to encourage education on septic tank maintenance and appropriate fertilizer application. This should be emphasized to homeowners and included in CCRs.

Acting Chairman Thompson asked for opponents.

Mike Hipsher, 875 Blackhawk Lake Dr, owns the furthest west lot in Blackhawk Lake. What is proposed would not affect Duffner Creek. The properties that would affect Duffner Creek are the ones in the border in the yellow along the western boundary [map in application]. Water quality is a concern; Blackhawk Lake is a pristine source which drains into the Payette River. He is concerned about the septic and fertilizer impacts. He wanted clarification if the yellow common areas and white areas on the map to be developed.

Mr. Dickens replied that this characterization is mostly correct.

Pete Fitzsimmons, 8 Sawtooth CT, (telephonically) owns property in both Blackhawk Ranch and Blackhawk Lake Estates. His concerns include watershed aquifer and wildland fire danger. He referred to today's *Star News* page 2 article about imposing development moratoriums in Valley County and the effects large developments have on public services. There has been rapid

expansion and negative impacts. This proposal would negatively impact the aquifer, watershed, and seasonal wildlife habitat.

Acting Chairman Thompson asked for rebuttal from the applicant.

Mr. Dickens stated that they are sympathetic of concerns but doesn't think adding an additional 135 homes will affect the neighborhood. Increasing the supply of homes and home sites is the solution to housing in Valley County.

Commissioner Roberts is concerned about the lack of central sewer and water in this large development. Traffic impacts and wildlife impacts need to be discussed. He does not think it is prudent to close the public hearing at this time.

The current application has individual water and septic. Valley County Code allows individual water and septic on one-acre subdivision lots. Written correspondence from applicant has offered up water and sewer. The adjacent Blackhawk Lake Estates 5 has individual septic systems.

These are things that the PZ Commissioners would like clarification on:

- A fact sheet addressing which lots would be central sewer and water, and which would be septic
- Address ID Fish and Game letter and how the applicant will comply, including CCRs
- Address traffic impacts
- DEQ and IDWR conversations and requirements
- Water quality concerns
- Central District Health requirements
- More concise picture of application
- Internal roads and previously approved variance for narrow roads
- Some analysis on soil types since water drains toward the river

The Planning and Zoning Commissioners would like the above information presented in a clear manner.

Sima Muroff, Meridian, ID, to respond to the discussion. He referred to his letter of January 10, 2022, which responded to comments in the staff reports and questions that Commissioners have mentioned tonight (**Exhibit 3**). Ground water monitoring was completed for two seasons; Central District Health approved 50 sites for septic systems. He said employees of both Idaho Department of Water Resources and Idaho Department of Environmental Quality said that this is not an area of concern for groundwater nor nitrates. Site specific analysis previously done by Secesh Engineer confirm this. The well log information confirm that the aquifer is not declining.

Commissioner Roberts is currently concerned with the surface water more so than the aquifer.

Mr. Muroff stated that the property is currently grazed by livestock. The applicant referred to the large maps of the application which show designated wetlands and additional common areas (**Exhibit 21**)

Mr. Dickens understands that the Commissioners wish for time to digest the extensive materials. Much of the work was previously done. The application was complete the first time but expired.

Commissioner Freeman moved to continue C.U.P. 21-45 Redridge Preserve to February 10, 2022, at 6:00 p.m. Commissioner Roberts seconded the motion. Motion carried unanimously.

1. Clarify pertinent attributes of the subdivision as it is being presented currently.
2. Letters from conversations with agencies, CDH, DEQ and/or IDWR.
3. Soil type data.
4. Concerned with septic and drainfields when sewer is so close. Sewer was not in application, but presented at the public hearing. Should they be compelled to connect to sewer since it is close? Recommend a hybrid and put smaller lots in first 3 phases on sewer.
5. Has a shared road agreement been met with Blackhawk 5?
6. How much of the construction on the previously approved Phase 1 has been completed?
7. Has a new or updated Wildfire Mitigation Plan been completed or submitted to P&Z?
8. Have any of the CDH requirements for test holes, groundwater monitoring, etc been started or completed or will this all be done as a condition of approval or a condition prior to recordation of the final plat?
9. Timing of phasing seems incredibly long for infrastructure traffic impacts on neighboring properties. Could this be shortened and extended as needed?
10. What level of bonding or financial assurance is expected?
11. What impact does being in a Herd district have on the property specifically as it relates to CC&R's related to fencing?
12. It sounds as though IDWR does not believe the aquifer would be negatively impacted with the addition of 135 additional private wells but can you further discuss the assessments that have been done to come to this conclusion?
13. Please discuss plans to preserve water quality that could impact Dufner Creek, Blackhawk Lake and the Payette River.
14. Is wetland delineation required?
15. Please further explain animal habitat considerations.
16. Would the development impact natural drainage throughout the area and if so please explain how this will be addressed?
17. Has any environmental impact study been completed? What has been done? A concern identified by neighbors.
18. Have the Valley County Engineers responded to the correct drawing set of preliminary site grading and drainage plans?
19. A fact sheet addressing which lots would be central sewer and water, and which would be septic
20. Address ID Fish and Game letter and how the applicant will comply, including CCRs
21. Address traffic impacts
22. DEQ and IDWR conversations and requirements
23. Water quality concerns
24. Central District Health requirements
25. More concise picture of application
26. Internal roads and previously approved variance for narrow roads
27. Some analysis on soil types since water drains toward the river



February 3rd 2022

Cynda Herrick, AICP, CFM  
Valley County  
Planning and Zoning Administrator  
Floodplain Coordinator  
219 N. Main St.  
PO Box 1350  
Cascade, ID 83611, o. (208)382-7116

RE: RedRidge Preserve CUP 21-45 Responses

Dear Cynda,

I reviewed the letters, and corresponding information mostly from home owners at our previously developed communities. Are there items of concern in them that pertain to us adjusting our application so it is compliant with the existing VALLEY COUNTY CODE?

Our CUP has been submitted with a thoughtful approach to the Environment and consistent with the VALLEY COUNTY CODE. Can staff be so kind as to point out the relevant items in our submittal that contradict the existing code so I may respond appropriately?

Meanwhile below is a summarized response to the Commissioners questions for clarification. Please also read the Letter to P&Z Dated January 10th 2021, and the attached Impact Report.

1. Has a shared road agreement been met with Blackhawk 5?

Our neighbor, Blackhawk Phase V CUP No. 20-02 subdivision was approved on March 20th 2020 with Individual well/septic. Their Density is approximately averaging 1 lot per 4.875 acres.

On January 7th 2022, P&Z Received a support letter from them for our CUP. We have a Road Agreement, See Instrument # 425069 Recorded 11-20-2019, Exhibit "B" to Special Warranty Deed ( 70' foot easement ), and the Support Letter from their counsel Mr. Wardle.

RedRidge Preserve's density is approximately averaging 1 lot per 11.95 acres.

2. How much of the construction on the previously approved Phase 1 has been completed?

Approximately 60% +/- . Gravel Pit drilled, & blasted, road has been cut, and Base Rock placed.



3. Has a new or updated Wildfire Mitigation Plan been completed or submitted to P&Z?

The previously approved WMP has been updated by John Lillehaug from All About Forestry, and is expected to be submitted next week.

4. Have any of the CDH requirements for test holes, groundwater monitoring, etc been started or completed or will this all be done as a condition of approval or a condition prior to recordation of the final plat?

The data from the Test Holes, Ground Water Monitoring Wells has been completed by Secesh Engineering. This has been submitted to CDH, and paid for. We will follow their guidance upon final review. There is no evidence suggesting that following VALLEY COUNTY CODE CHAPTER 4 PERMITTED USES, 9-4-3-1: LOT AREA:, & 9-4-3-4: SITE IMPROVEMENTS: will be non compliant with the VALLEY COUNTY CODE ,CDH, or DEQ.

5. Clarify: all septs and wells or a hybrid? Based on the recommendations of DEQ I think it would be worth considering a hybrid system or fully on a central system if possible?

VALLEY COUNTY CODE CHAPTER 4 PERMITTED USES, permits minimum lot sizes of 1 acre with individual wells/septs. Our minimum lot sizes are 3 acres. Central water, & Sewer is not available at this time. The CUP was designed, and Engineered to follow VALLEY COUNTY CODE CHAPTER 4 PERMITTED USES, and other applicable Ordinances.

6. Timing of phasing seems incredibly long for infrastructure traffic impacts on neighboring properties. Could this be shortened and extended as needed?

Yes we will, strive to complete the CUP in 10 years.

7. What level of bonding or financial assurance is expected?

We will follow the County Code and your Guidance on financial assurances, where our Engineer recommends, or as needed such as bonding the final portions of construction.

8. What impact does being in a Herd district have on the property specifically as it relates to CC&R's related to fencing?

RedRidge Preserve has an existing robust native terrestrial ecology, and plans on working with Stakeholders such as Harry Soulen, the County, Idaho Fish and Game etc. in repairing the existing perimeter fencing.

RedRidge Preserve's CC&R's will have Landscape guidelines directing homeowners to the Valley County Ordinances:

9-4-3-4: SITE IMPROVEMENTS: F. Best Management Practices:  
9-5A-4: LANDSCAPING: SITE PLAN:  
9-5A-5: FENCING:

9. It sounds as though IDWR does not believe the aquifer would be negatively impacted with the addition of 135 additional private wells but can you further discuss the assessments that have been done to come to this conclusion?

The IDWR Senior Agent has confirmed this area is not in a State of Idaho Area of Water, or Nitrate Concern. Also A preliminary Groundwater resource evaluation was performed by SPF Water Engineering, LLC, and submitted as part of this CUP. Based on this Report, there does not appear to be evidence suggesting a Declining underground water aquifer.

Our neighbor Blackhawk Phase V's density is approximately averaging 1 lot per 4.875 acres. Our density is approximately averaging 1 lot per 11.95 acres.

- 
10. Please discuss plans to preserve water quality that could impact Dufner Creek, Blackhawk Lake and the Payette River.

No homes will be allowed to be built within the Dufner Creek Riparian Zone, or other identified sensitive riparian areas.

Drainage will be designed in accordance with the design standards stated in the Valley County Minimum Standards for Private Road Design and Construction.

11. Is wetland delineation required?

The wetlands at Redridge Preserve have been delineated in the field and are shown on the preliminary plat maps. This on site delineation map has been reviewed and approved by the U.S. Army Corps of Engineers. We will work with the U.S. Army Corps of Engineers with any needed additional requirements.

12. Please further explain animal habitat considerations

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I spoke to Casey Pozzanghera, the Idaho Fish and Game Environmental Staff Biologist. We have agreed to work with him and his staff to produce acceptable CC&R language that implements his thoughts on the:

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WildLife Movement & Fencing,  
Vegetation and,  
General Considerations.

13. Would the development impact natural drainage throughout the area and if so please explain how this will be addressed?

Drainage in excess of pre-development volumes and flow rates will be retained and/or detained on site and discharged at predevelopment rates to protect downstream properties. Drainage will be designed in accordance with the design standards stated in the Valley County Minimum Standards for Private Road Design and Construction.

Storm water will be treated through approved BMPs and then disposed in accordance with the "Handbook of Valley County Storm Water Best Management Practices."

14. Has any environmental impact study been completed?

Please read the Letter to P&Z Dated January 10th 2021, and the attached Impact Report.

- 
15. Have the Valley County Engineers responded to the correct drawing set of preliminary site grading and drainage plans?

Yes they have, we will follow their guidance and comply with the County Engineers recommendations as described below.

The preliminary plans require signed and sealed drainage calculations reflecting the updated site grading and drainage design with a new 2022 stamp/seal.

We will comply with all conditions of the Valley County Private Road Standards

I really appreciate your thoughtful consideration of our application, and appreciate any recommended suggestions in order for it to comply with the VALLEY COUNTY CODE.

Thank you,

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Sima Muroff



# **REDRIDGE PRESERVE**

**A Conservation Oriented Community**

## **IMPACT REPORT**

The RedRidge Preserve Community, as planned, meets the goals of the Comprehensive Plan, planning policy and the requirements of the Valley County Land Use and Development Ordinance with minimal impacts as required by Valley County.

### **A. TRAFFIC**

West Mountain Road is the main road providing access and connectivity to the surrounding communities and highways and to RedRidge Preserve Community. A new looped roadway, Redridge Loop, will connect RedRidge Preserve Community to West Mountain Road near the Blackhawk on the River development to the north and through the approved Blackhawk Lake 5 development to the south. An Easement has been recorded between TMA, and Tommy Alhquist, with the County to access West Mountain Road through the his Blackhawk Lake 5 development. The Owners intend to construct the entire length of Redridge Loop to a finished base course surface in conjunction with the first phase of lot development. That portion of Redridge Loop from the north access to West Mountain Road through the first phase is planned to be paved.

All roads within the RedRidge Preserve Community development will be private local roads with proposed 20-feet of asphalt paving and 2-foot gravel shoulders. The reduced roadway section from 4-foot shoulders to 2-foot shoulders is desired to minimize the need for cut and fill slopes in steeper terrain, but still providing safe access for the residents and emergency response equipment. With this application, the Owners are requesting a variance from the Valley County Minimum Standards for Private Road Design and Construction standards. The Owners also request the ability to work with the Valley County Engineer and Roadway Supervisor to evaluate the use of other possible finished surfaces, realizing that the minimum standards do not require the use of asphalt for the finished surface.

The RedRidge Preserve Community development will contain 135 single family residential lots. At project build-out, and due to the recreational nature of the development, anticipated added average daily vehicle trips traveling on West Mountain Road is less than 700 trips per day. West Mountain Road is adequate to accommodate the anticipated increased traffic that this development will generate. West Mountain Road is currently paved from the intersection with Blackhawk Lake Road to the city of McCall. The final construction of approximately 5,600 additional feet of paved roadway from the Blackhawk Lake Road intersection to the south has been mostly completed.

The project entrance, off of West Mountain Road, is anticipated to be monumented. These monuments will identify the development to the public and add to the aesthetics of the project.

## **B. COMMUNITY HOUSING**

The developers of RedRidge Preserve Community are not proposing any community housing.

## **C. NOISE AND VIBRATION**

The site is currently undeveloped forest and range land and there are no significant levels of noise and vibration associated with the existing use. During periods of construction of the subdivision infrastructure and new housing construction, there will be a short term increase in noise and

vibration levels. However, these increases are expected to be normal levels for the type of work being performed and these noise levels will be mitigated by restricting construction activities to normal working periods of the day and the work week. Long term increases resulting from daily activities of the residents of the development are anticipated to be minimal. These noise and vibration levels will be consistent with the standards set forth in the Valley County Land Use and Development Ordinance and in keeping with current activities from previous development in the area.

#### **D. HEAT AND GLARE**

In the short term of the infrastructure and building construction there may be a slight increased glare. Heat and glare should be minimized to the greatest extent possible through the project site planning, building orientations and materials.

#### **E. AIR QUALITY**

During the construction periods of the development for infrastructure and new housing construction, there will be a short term increase in the potential for dust, smoke, and construction equipment emission levels. However, these increases are expected to be normal levels for the type of work being performed and these levels will be mitigated through strict dust abatement requirements, maintaining construction equipment for optimum performance and minimization of fume emissions and through restricted construction activities to normal working periods of the day and the work week. All construction of new housing in Valley County presents the potential for increases of pollutants from wood burning stoves and outdoor fireplaces and burning. The RedRidge Preserve Community development will have enforceable non-burn periods when air quality levels are degraded. Through the CC&Rs, the governing board for the development will have the ability and responsibility to order burning bans to all residents within the development. The board will work with the Division of Environmental Quality to establish guidelines and access to monitoring data, to implement this program.

#### **F. WATER SUPPLY AND DEMAND**



Domestic water will be provided by individual wells located on each residential lot. These wells will be constructed and maintained by the home owner. A preliminary Ground water resource evaluation was performed by SPF Water Engineering, LLC, see Appendix A-1. It is anticipated that wells can be drilled on each individual lot that will provide adequate supply for residential use. Testing on existing wells in the areas shows that the groundwater quality is generally good and it is anticipated that the water quality will be adequate for domestic use.

## **G. FIRE PROTECTION**

There are no activities that require the routine burning of debris and there are no explosive materials stored, or used on this site.

In accordance with coordination with the McCall Fire Department, Fire suppression water will be supplied from across West Mtn. Road at the Blackhawk on the River community. The remote supply systems will include:

1. The existing community pressure supply system for Blackhawk on the River.
2. Extension of Hydrants and water lines from West Mtn. Sewer & Water, Inc. and Blackhawk on the River, as coordinated and approved by the McCall/Donnelly Fire Marshall.

Additional fire protection will be required through the CCR's for defensible buffer zones around structure perimeters and in the use of fireproof building materials.

## **H. SOLID WASTE**

This development should not adversely impact the existing solid waste transfer station or the private collection operation. The solid waste collection for the residents within this development will function similar to other Valley County property owners. Participation in recycling programs will help minimize the development's overall waste production.

## **I. SANITARY SEWER SYSTEM**

Sewage collection and treatment will be provided by individual sewage disposal systems located on each residential lot. Individual systems will be constructed and maintained by the home owner.

The Idaho Department of Environmental Quality and Central District Health Department Rules and Regulations stipulate that Nutrient-Pathogen Studies are not required for residential developments with minimum lot sizes of 3 acres or greater. Developments of this low density that utilize individual sewage disposal systems within the complete range of suitable soils types have been determined to have negligible impact on surrounding and down-gradient properties and water bodies. Based on these current rules, a Nutrient Pathogen Study was not performed for this application. Monitoring wells have been established throughout the site to verify the soil compatibility for potential treatment sites on each residential lot. An area will be located on each lot that meets the requirements for treatment. Each area will be exposed, inspected and approved for the intended sewage treatment and disposal system by the local health department official prior to issuance of a building permit.

## **J. FLOOD POTENTIAL**

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RedRidge Preserve Community is located on land west of West Mountain Road and the Payette River. The lowest elevation of a residential lot is approximately 50 feet above the Payette River 100-Year Floodplain. Therefore, there is no flood risk within the limits of the development other than flows associated with winter snow melt. These flows are considered minor in nature and are not reflected on flood maps. Culverts for the conveyance of these flows will take into consideration peak runoff. New home sites will be located well above these channels to protect structures from seasonal runoff.

## **K. DRAINAGE PATTERN / WATER QUALITY**

The subject property currently consists of steep to moderately sloping forested land that consists of multiple minor drainages most of which drain to Duffner Creek, Blackhawk Lake or Mill Creek. Duffner Creek enters the site approximately at the midpoint of the north boundary and flows in a southerly direction to Blackhawk Lake, a.k.a Hait Reservoir through the developed area. Several other minor drainages located to the west and

south of Blackhawk Lake also flow to Blackhawk Lake. Discharge from Blackhawk Lake is regulated. This discharge crosses West Mountain Road and flows through the South Ranch to the North Fork of the Payette River.

The remaining area south of Blackhawk Lake that does not drain to Blackhawk Lake consists of several minor drainages that drain into Mill Creek. Mill Creek crosses West Mountain Road at a location outside the property boundary and then flows to the North Fork of the Payette River.

Drainage in excess of pre-development volumes and flow rates will be retained and/or detained on site and discharged at predevelopment rates to protect downstream properties.

Drainage will be designed in accordance with the design standards stated in the Valley County Minimum Standards for Private Road Design and Construction.

Storm water will be treated through approved BMPs and then disposed in accordance with the "Handbook of Valley County Storm Water Best Management Practices." BMPs will be used to naturally filter pollutants, and provide nutrient uptake before storm water enters the existing drainage patterns. In addition, surface water quality will be addressed during and after construction of the development. Improvements will focus on limiting the area of disturbance and treating the surface water as close to the source as possible. Storm Water Pollution Prevention Plans will be prepared and complied with throughout the course of construction to protect the site and surrounding properties from uncontrolled runoff.

## **L. WETLAND AREAS**

There are minimal existing wetlands located within the development site. These wetlands have been delineated in the field and are shown on the preliminary plat maps. This on site delineation map has been reviewed and approved by the U.S. Army Corps of Engineers. Through careful site planning, the proposed improvements will avoid these wetlands to the greatest extent possible and incorporate the wetlands into common open space. With the exception of roadway crossings, the proposed layout locates all new improvements outside of the wetlands. The roadway crossing areas will be totally mitigated with like quantities and types of wetlands in areas adjacent to existing wetlands that will be retained. The

mitigation areas of the site appear to provide favorable hydrology and soils conditions for riparian and wetland area rehabilitation and mitigation. All proposed wetland encroachments and planned mitigation will be submitted to and approved by the U.S. Army Corps of Engineers for compliance with Section 404 of the Clean Water Act. Approval will be secured, prior to impacting any of the on- site wetlands.

## **M. SOIL CHARACTERISTICS**

Soils groups within the site are typically Demast Loam on the east facing slopes of Red Ridge, Sudduth Variant Loam on the lower and flatter slopes, and Tica very Cobbly Loam on the middle and easterly slopes of the site. As listed, these soils tend to be loams to clay loams, typically underlain by fractured basalt to bedrock. These soils groups appear to be suitable for the intended improvements, however, specific site selection for suitable on site sanitary sewer disposal will be required and is ongoing. A preliminary geotechnical evaluation has been conducted and is included in this application. This report has been prepared to assist the architect and engineer with preliminary design criteria associated with site improvements. A detailed final report will be prepared following approval of this application. A detailed Erosion Control Plan, to be followed throughout the course of the project development, will be designed and implemented to avoid potential erosion and soils instability problems.

## **N. SITE GRADING**

Site grading will be designed, where possible, to minimize land disturbance and retain natural site features. To minimize road grading, where possible new roads will replace existing dirt and/or gravel roads. Grading of individual residential building pads and lots will not take place during the construction of subdivision infrastructure and roadway improvements. Residential lot grading will be designed based on the individual home design and access requirements to the home. Lot grading for the residential lots will be conducted with the construction of the individual home. Disturbed areas associated with utility and roadway construction will be carefully graded and revegetated to protect against site erosion and

discharge of sediments. Both the CC&R's and the Design Guidelines will require review of any significant site grading that might alter the site and impact adjacent dwelling lots and common areas, by the Architectural Review Committee. Final grading plans will be submitted for review and approval with the final plat for each construction phase of the project.

## **O. VEGETATION**

This site is covered with a mixture of upland grasses, sage brush, bitter brush, and pine trees. The developers intend to maintain and protect this vegetation to the greatest extent possible. The goal of the development will be to create an environment that is harmonious with the existing landscape.

Existing forested areas will be maintained to the greatest extent possible. Clear cutting for maximized building pad location will NOT be the practice other than for the proper creation of defensible zones around the new dwellings and other structures. Grading of lots for building pads will be done at the time of house construction to exactly locate the building site and retain, to the greatest extent possible, the existing forested slopes.

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## **P. FISH AND WILDLIFE**

This development is anticipated to have minimal impact to existing fish and wildlife populations and habitat. Fencing in and around this development area will be restricted, through the CCR's, which will allow the free movement of wildlife in and around the development.

## **Q. VISIBILITY TO DEVELOPMENT**

The developers have located, to the greatest extent possible, home sites away from West Mountain Road, the primary vehicle route in this area. The developers intend to retain and protect a maximum amount of existing forested slopes to preserve the natural appearance and provide a private setting for new residents. The entrance to the development is proposed to be monumented, which will be designed to enhance the entrance to the development.

## **R. SITE SELECTION**



This site is located adjacent to and generally west of the Blackhawk Lake Estates subdivision and the newly built Blackhawk Lake 5 subdivision. All other surrounding properties are undeveloped forested rangeland. The total acreage owned by The McCall Associates, LLC is approximately 2886 acres. Of the 2886 acres, the approximate northerly 1614 acres make up the RedRidge Preserve Community Subdivision. The remaining southerly 1266 acres has been earmarked as future development. The original vision of Cranberry Ridge, LLC, planned to develop the entire 2890 acres (see, original proposed layout) into a mixed use single family residential to multi-family residential with a multi-unit hotel site and 18-hole golf course. The layout as proposed with this preliminary plat eliminates the multi-unit concept and the golf course, resulting in a lower density concept. The McCall Associates, LLC man however chose to cluster higher density where warranted and reserves this right in the future.

This project site offers diversity in natural features, access to nearby public roads and close proximity to the existing Blackhawk community.

## **S. MARKET NEED**

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Market research shows that there is a continued demand for an upscale development of this caliber with the amenities that RedRidge Preserve Community has to offer, for both personal and investment purposes. The "Baby boomer" generation which controls approximately 80% of the country's wealth, is moving their money into more secure forms of investments, specifically government backed bonds and vacation/retirement real estate. This demand has been supported through recent sales at the nearby Blackhawk on the River, Tamarack, and other high end properties neighboring McCall. RedRidge Preserve Community has natural beauty and mystique that is attractive to those buyers interested in the Idaho lifestyle, the state's history, and the welcoming community of Valley County. The RedRidge Preserve Community development has substantial amenities throughout, that is unique to this property and highly desired by potential homeowners.

The topographical layout of the property is outstanding, as the design uses the elevation changes to give homeowners views of the surrounding mountains, river, open spaces, wetlands, and common areas. Miles of



planned walking and equestrian trails will meander throughout the property. These trails will eventually connect to Blackhawk Ridge and to the rest of the Blackhawk property in order to create the "community" feel that we strive to achieve.

#### **T. ANTICIPATED RANGE OF SALES**

RedRidge Preserve Community will consist of 135 single family home sites, ranging from approximately 3 acre to as large as 15 acres in size. These home sites are going to be priced based on market demand. The price point for forested 3-acre lots are expected to begin at \$300,000. Larger view and Bluff lots will be priced up to \$1,000,000.

#### **U. PROPOSED PHASING**

The Phasing Plan for RedRidge Preserve Community consists of 10 proposed phases. Phase 1 is proposed to consist of about 30 residential lots in the north portion of the site and will be accessed from West Mountain Road.

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Subsequent phases are proposed to be brought on every other year, or as the market allows, developing the entire site over a 10 to 20 year period. The McCall Associates, LLC request the ability to modify the phasing boundaries as needed, to account for demand and other possible unforeseen conditions.

#### **V. PROPOSED FINANCING**

The McCall Associates, LLC plans to finance this project with its own capital, private funds, and conventional lender financing, in order to acquire, maintain, and develop the project.

#### **W. PROPOSED CONSTRUCTION SCHEDULE**

The initial Phase 1 project, will merge Phase 1,2,3 consisting of 30 building lots, and the construction of Elderberry Road to finished base course, is proposed to begin during the construction season of 2022, as soon as site

conditions will allow. This initial phase is anticipated to be completed for lot sales by 2023 and new home construction to begin during the 2023 prime construction season. The remaining phases are projected as follows, based on the latest anticipated schedule:

**Latest Projected Schedule**

Phase		Construction	Platting
Phase 1	10 Lots	2022	2022
Phase 2	13 Lots	2022	2022
Phase 3	7 Lots	2022	2022
Phase 4	16 Lots	2024	2026
Phase 5	9 Lots	2027	2028
Phase 6	16 Lots	2029	2030
Phase 7	13 Lots	2031	2032
Phase 8	30 Lots	2033	2034
Phase 9	9 Lots	2035	2036
Phase 10	12 Lots	2037	2042
135 Lots			

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**X. PUBLIC SERVICES**

This development is a private venture to be financed through private funds. No public funds will be required for the construction of the site improvements. The project will include individual water and sewer systems, which will not pose added cost burdens to the county. Other public services include telephone and power service, which will also be extended to the site at the developer's cost.

**Y. BENEFITS VS. COSTS**

Our anticipated engineering and construction costs to build out RedRidge Preserve Community, based on today's projected costs, are expected to be approximately \$15,000,000 for improvements. Sales, based on today's forecasts range from \$67,000,000 to \$83,000,000. Given the current building guidelines, we anticipate home prices to range between \$850,000 and \$2,000,000. The corresponding economic build out of RedRidge

Preserve Community is estimated to be between \$182,000,000 to \$229,000,000 upon the completion and sale of the entire 135 homes.

JG Market Research has been contracted to define the demand, feasibility, and demographic needs of potential buyers of RedRidge Preserve Community home sites. Preliminary data supplied by JG suggests that our client is well educated, well traveled, affluent, and approaching retirement age. This clientele comes from all over the world, however, is predominantly made up of 2<sup>nd</sup> home, and vacation home purchasers west of the Rockies. The benefits of this development to Valley County, its businesses, and the local community of McCall are significant. These benefits arise from an elevated tax base, due to the real estate sales, and subsequent taxes collected on these properties. In addition, the out of town cash infusion to the local economy by new homeowners will be beneficial to both business owners, and local employment. We project our home owners will contribute to the local economy through the purchase of goods and services which should remain consistent with those national averages of similar "high end" resort properties, at slightly over \$150 per day, per individual.

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## **Z. NATURAL RESOURCE**

Natural resources at this site include the existing site topography, forested slopes, seasonal water channels, existing wetlands and the underground soils types.

The existing site topography includes multiple naturally occurring ridgelines that runs north to south and west of West Mountain Road. The ridgelines will be retained for home sites that will be afforded privacy and in many sites, premium views of the surrounding area. Minor impacted areas to the ridgeline will include the required roadway locations that access home sites. To the greatest extent possible, home sites and roadways will be located within the forested areas to minimize the visual impact of roadways through the open meadow areas of the site.

January 10th 2021

Cynda Herrick, AICP, CFM  
Valley County  
Planning and Zoning Administrator  
Floodplain Coordinator  
219 N. Main St.  
PO Box 1350  
Cascade, ID 83611, o. (208)382-7116

RE: Red Ridge CUP 21-45 Staff Report Responses

Dear Cynda,

I have reviewed the responses during the public comment period. I understand it is closed now, although I would appreciate you adding this letter into the record.

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(IWUIC)

RedRidge CUP 21-45 Staff Report Responses

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I have communicated with the respondent Agency Heads, and additional Governmental Agencies such as Idaho Department of Water Resources (" IDWR").

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Mr. Skinner from IDWR the Senior Agent has confirmed this area is not in a State of Idaho Area of Water, or Nitrate Concern, having said that removing livestock from the property will decrease Nitrates. A preliminary Groundwater resource evaluation was performed by SPF Water Engineering, LLC, and submitted as part of this CUP. It is anticipated that wells can be drilled on each individual lot that will provide adequate supply for residential use. Testing on existing wells in the areas shows that the groundwater quality is generally good and it is anticipated that the water quality will be adequate for domestic use. Also based on this Report, there does not appear to be evidence suggesting a Declining underground water aquifer.

**Septic:**

Central District Health confirmed they have the application, and fees have been paid for 50 lot's ( this more than covers Phase-1 ). CDH did not have the completed Test Pit, or Monitoring Data. I submitted that to them, and will work with them to complete their approval process.

**Staff Report FINDINGS:**

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I will work with Jeff McFadden, the Road Department Director, on the approach permit.

As explained above we are working with Garrett de Jong, & Jess Ellis, there are approximately 10 lots in the final phases of the development that are in the Donnelly Rural Fire Protection District. Assuming both departments are supportive, we would like to annex that section into the McCall Fire District. We will work to follow the procedures to accomplish that.

We will show relevant easements on the Plat.

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seem to be any complaints, or reports of any kind as it relates to the neighboring development's pre & post construction activities. Also, per some of the neighborhood comments submitted, he did confirm:

1. This area is not in a nitrate priority area.
2. If concerns exist over nitrates, removing livestock from the property will decrease them.
3. Deleterious materials are not a real concern in normal construction of roads, and homes.

Per Guidance from the Valley Soil and Water Conservation District, we will manage surface water so as to provide irrigation for lawns to create a green defueling area around the home for fire protection. CCR's will address standard requirements for septic systems and management.

I spoke to Casey Pozzanghera, the Idaho Fish and Game Environmental Staff Biologist. We have agreed to work with him and his staff to produce acceptable CC&R language that implements his thoughts on the:

WildLife Movement & Fencing,  
Vegetation and,  
General Considerations.

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4. We appreciate Pete Fitzsimmons comments, we will follow the Department of Environmental Quality Ground Water Quality Rule as described in IDAPA 58.01.11 . Which states:

"No person shall cause or allow the release, spilling, leaking, emission, discharge, escape, leaching, or disposal of a contaminant into the environment in a manner that:

- 
- Causes a ground water quality standard to be exceeded;
  - Injures a beneficial use of groundwater; or

- Is not in accordance with a permit, consent order or applicable best management practice, best available method or best practical method.

## 7. Valley County Code (Title 9):

In Table 9-3-1, this proposal is categorized under:

2. Residential Uses (c) Subdivision for single-family subdivision.

*Surrounding Uses:*

**VALLEY COUNTY CODE TITLE 10 SUBDIVISION REGULATIONS**

**10-1-5: COMPLIANCE WITH COUNTY COMPREHENSIVE PLAN:**

RedRidge Preserve CUP is located near the McCall City Impact Area, and surrounded to the East, & South with existing Residential Subdivisions. Therefore we believe the CUP meets it's requirements for 10-1-5.

## 9-5A-1: GRADING:

Each Estate Site will be graded to have a reasonably flat spot for a structure/septic and a driveway that is 8% or less.

**A PDF of the grading plans** have been submitted to the County Engineer on 1-10-21. We acknowledge a conditional use permit is required prior to the start of such an activity.

**D. Wetlands:** There are minimal existing wetlands located within the development site. These wetlands have been delineated in the field and are shown on the preliminary plat maps. This on site delineation map has been reviewed and approved by the U.S. Army Corps of Engineers. Any proposed wetland encroachments and planned mitigation will be submitted to and approved by the U.S. Army Corps of Engineers for compliance with Section 404 of the Clean Water Act. Approval will be secured, prior to impacting any of the on- site wetlands.

**G. Stormwater Management Plan:** Prior to issuance of permits County and County Engineer will receive a certification from our engineer verifying that the stormwater management plan has been implemented according to approved plans.

## STAFF COMMENTS / QUESTIONS:

1. ok

2. Redridge Preserve is located on land west of West Mountain Road and the Payette River. The lowest elevation of a residential lot is approximately 50 feet

above the Payette River 100-Year Floodplain. Therefore, there is no flood risk within the limits of the development other than flows associated with winter snow melt. These flows are considered minor in nature and are not reflected on flood maps. Culverts for the conveyance of these flows will take into consideration peak runoff. New home sites will be located well above these channels to protect structures from seasonal runoff.

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4. Only one wood-burning device will be allowed and noted on plat. CCR's will address fertilizers, fire resistant building materials, firewise landscaping, maintenance and continued implementation of the Wildfire Mitigation Plan, & building envelopes. CCR's also address long-term maintenance of septic systems.
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15. We will work with stakeholders on snowmobile access along the furthest southerly border of the property.
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## Conditions of Approval

1. ok
2. ok
3. ok
4. ok
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6. ok
7. ok
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18. ok

Please review this and let me know if you need some additional clarification or data to submit.

Sincerely,

Blackhawk Manager, LLC

2022  
January 10th 2021

RECEIVED  
JAN. 10, 2022  
RH

Cynda Herrick, AICP, CFM  
Valley County  
Planning and Zoning Administrator  
Floodplain Coordinator  
219 N. Main St.  
PO Box 1350  
Cascade, ID 83611, o. (208)382-7116

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Sincerely,

Blackhawk Manager, LLC

**From:** S M <[REDACTED]>  
**Sent:** Friday, January 14, 2022 11:31 AM  
**To:** Cynda Herrick <cherrick@co.valley.id.us>  
**Cc:** Brian Dickens, Indep. CEO <[REDACTED]>  
**Subject:** Follow Up

Hy Cynda,

Great to see you last night and the rest of the commissioners. Thanks for briefing me this morning. I will finish up the concise lazer accurate summary, and await Commissioner Childs' questions.

1. 135 lots average 6 acres in size ( reference ordinance title section )
2. No Central Water/Sewer ( reference ordinance title section )
3. Fire Suppression through extension of WMSW Hydrants ( show map )
4. Soils summary (this is in the FMP, and Impact Report)
5. CDH File on 50 approved lots for septic already (we have this)
6. County Engineer to review the complete engineering and issue a custom letter, standard template ( can you authorize him to do this?)

Thank you,

---

Sima Muroff  
Blackhawk Manager, LLC Owner



WMSW, Inc.

S M [REDACTED]

Mon 1/31/2022 10:59 AM

To: [REDACTED]

Cc: [REDACTED]

**CAUTION:** This email originated from outside of the organization. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Hi Gary,

Good morning, it was great to catch up this morning.

I appreciate you confirming that we are in good standing with DEQ. I understand that the youtube video ( P&Z Hearing ) you watched may be a bit confusing on whether or not RedRidge Preserve CUP 21-45 is relying on WMSW, Inc, for it's sewer needs.

Just to clear up any confusion, at this time RedRidge Preserve CUP 21-45 is not contemplating a sewer connection to WMSW, Inc. It's application is based on the existing Valley County Code for Individual Wells, & Septic, which are allowed on lot's with a minimum of 1 acre. None of the Lot's at RedRidge Preserve are under 3 acres. See below:

---

VALLEY COUNTY SUBDIVISION ORDINANCE, AS AMENDED IN 2010. (Ord. 10-07, 8-26-2010)GENERAL PROVISIONS

**9-4-3: STANDARDS:, 9-4-3-1: LOT AREA:**

B. Single-Family Residence: However, in no case, shall a single- family residence be located on a lot split from a platted lot or on a parcel of land divided from an original parcel without platting that is less than one acre in area where individual sewage disposal and individual water supply system are proposed. (Ord. 10-06, 8-23-2010)

RedRidge Preserve CUP 21-45 is however proposing to tie into the existing Hydrant at WMSW, Inc. for its Fire Suppression needs. If for some reason the minimum Fire Flow requirements, and necessary Water Rights do not exist then we will be constructing a new Well at the RedRidge Preserve project to service it's Fire Suppression needs.

BTW,

I found that list for Nitrate Priority Areas "NPA"'s, and confirmed WE ARE NOT IN ONE. <https://www2.deq.idaho.gov/admin/LEIA/api/document/download/14705>

If you have any questions please don't hesitate to call me or Mr. Dickens, or email him which I also cced in this email.

Sincerely,

Sima [REDACTED]

From: S M [REDACTED]  
Sent: Monday, January 31, 2022 12:06 PM  
To: Cynda Herrick <cherrick@co.valley.id.us>  
Cc: [REDACTED]  
Subject: Water Quality Discussion

Hi Cynda,

After reviewing the papers sent by DEQ (see attached) for discussion of water quality in Valley County the only Study that is specific to Valley County would be the one entitled: "Livestock\_Grazing\_Effects\_on\_Phosphorus\_Cycling\_in\_Watersheds\_Shewmaker\_1999", which on page 58 supports Livestock Grazing ("Livestock grazing, assuming it's performed with BMP's, in fact removes P from the ecosystem, thereby reducing the extractable soil P.")

These do not discuss the benefits of installing Septic Systems, and removing livestock, or how Idaho is the most Stringent in the NW for it's individual on site septic requirements. RedRidge Preserve homeowners will be following the State and County requirements for individual septs, and DEQ has not identified any concerns with Septic Systems installed at RedRidge Preserve. In fact to the contrary there is growing support to reduce the requirements Idaho has for individual septic's.

I would propose that if the County is concerned about Nitrogen, Phosphorus, & Pathogens they focus on the Livestock/Farming activities, Open Range Laws, and as it relates to RedRidge Preserve specifically the 9-15-1920 WB Boydstun Herd District (see attached). The BMP's recommended for Livestock Operations seem to consist of Fencing, and Phosphorus (P) runoff from Farms. The Livestock/Farming BMP's discussed are aimed at reducing P through reductions in erosion or entrapment of P within the terrestrial landscape ( shrubs, vegetation, etc. ).

RedRidge Preserve has an existing robust native terrestrial ecology, and plans on working with Stakeholders such as Harry Soulen, the County, Idaho Fish and Game etc. in repairing the existing perimeter fencing.

RedRidge Preserve's CC&R's will have Landscape guidelines directing homeowners to the Valley County Ordinances:

- 9-4-3-4: SITE IMPROVEMENTS: F. Best Management Practices:
- 9-5A-4: LANDSCAPING: SITE PLAN:
- 9-5A-5: FENCING:

Our CC&R's will request buffer zones, such as grass and vegetative filter strips, protection of riparian zones and wetlands where necessary. The homeowners will be required to submit a Landscaping site plan that conforms with the Valley County Ordinances for Landscaping, Fencing, BMP's, and Wildfire Protection, as well as those appropriate that the Idaho Fish and Game staff produce that implements there thoughts on the:

- WildLife Movement & Fencing, Vegetation and,
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Thank you,

Sima [REDACTED]

T.18N.  
1" = 1 mile

To New Meadows  
8.8 Miles

1" = 1 mile

**Libri.**

PAYETTE

McCALL  
Pop. 2188  
5021

McCall  
Airport  
5023'

W.B. BOYDSTUN  
HERD DISTRICT  
SEPT. 15, 1920  
Bk. 1, Pg. 299

"It will be unlawful to permit cattle, sheep, or hogs to run at large or be herded in the lanes of the boundaries of the said district between the first day of April and the first day of November each year."

DRAWN BY: V.C. ENGINEER DEPT.  
NOV.1989 SHEET 1 OF 6



University of Nebraska - Lincoln

DigitalCommons@University of Nebraska - Lincoln

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Publications from USDA-ARS / UNL Faculty

U.S. Department of Agriculture: Agricultural  
Research Service, Lincoln, Nebraska

2004

## Water Quality and the Grazing Animal

R. K. Hubbard

*Southeast Watershed Research Laboratory, USDA-ARS, Tifton, GA*

G. L. Newton

*University of Georgia, Tifton*

G. M. Hill

*University of Georgia, Tifton*

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# Water quality and the grazing animal<sup>1</sup>

R. K. Hubbard\*<sup>2</sup>, G. L. Newton†, and G. M. Hill†

\*Southeast Watershed Research Laboratory, USDA-ARS, Tifton, GA 31793 and

†Department of Animal and Dairy Science, University of Georgia, Tifton 31793

**ABSTRACT:** Grazing animals and pasture production can affect water quality both positively and negatively. Good management practices for forage production protect the soil surface from erosion compared with conventionally produced crops. Grazing animals and pasture production can negatively affect water quality through erosion and sediment transport into surface waters, through nutrients from urine and feces dropped by the animals and fertility practices associated with production of high-quality pasture, and through pathogens from the wastes. Erosion and sediment transport is primarily associated with high-density stocking and/or poor forage stands. The two nutrients of primary concern relating to animal production are N and P. Nitrogen is of concern because high concentrations in drinking water in the NO<sub>3</sub> form cause methemoglobinemia (blue baby disease), whereas other forms of N (primarily nitrite, NO<sub>2</sub>) are considered to be potentially carcinogenic. Phosphorus in the PO<sub>4</sub> form is of concern because it causes eutrophication of surface water bodies. The effect of grazing animals on soil and water quality must be evaluated at both the field and water-

shed scales. Such evaluation must account for both direct input of animal wastes from the grazing animal and also applications of inorganic fertilizers to produce quality pastures. Watershed-scale studies have primarily used the approach of nutrient loadings per land area and nutrient removals as livestock harvests. A number of studies have measured nutrient loads in surface runoff from grazed land and compared loads with other land uses, including row crop agriculture and forestry. Concentrations in discharge have been regressed against standard grazing animal units per land area. Watersheds with concentrated livestock populations have been shown to discharge as much as 5 to 10 times more nutrients than watersheds in cropland or forestry. The other major water quality concern with grazing animals is pathogens, which may move from the wastes into surface water bodies or ground water. Major surface water quality problems associated with pathogens have been associated with grazing animals, particularly when they are not fenced out from streams and farm ponds. This paper presents an overview of water quality issues relating to grazing animals.

**Key Words:** Forages, Manure, Nitrogen, Pathogens, Phosphorus, Sediment

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## Introduction

Pollution of surface and ground waters from animal wastes is of growing environmental concern. High loading rates of sediment, N, P, and pathogens to soils and waters can occur from animal operations, such as grazing (Besser et al., 1993; Isaacson et al., 1993; Millard et al. 1994, Guan and Holley, 2003). Concentrations of N in excess of 10 mg/L in the nitrate (NO<sub>3</sub>) form render groundwater unsuitable for drinking water for humans

(Abbott, 1949; Lenain, 1967; Federal Register, 1975). High N concentrations entering streams or lakes may also contribute to eutrophication. Phosphate is adsorbed onto sediments and can be transported with the sediments to lakes and streams where its most significant effect is eutrophication (Clark et al., 1985). Animal waste has been shown to be a source of microorganisms pathogenic to humans (Howell et al., 1995; 1996; Mawdsley et al., 1995; Fraser et al., 1998). When surface runoff or leaching occurs due to excessive irrigation or rainfall, contamination of water resources by enteric bacteria may result (Entry et al., 1999). These same bodies of water are often used for sources of drinking water or for recreational activities; therefore, elevated concentrations of enteric bacteria pose a potential health hazard.

The amount of wet feces produced per 1,000 kg of animal live weight per day for grazing animals ranges from 40 to 86 kg for sheep and dairy cattle respectively

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<sup>2</sup>Corresponding author—hubbard@tifton.usda.gov.

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Table 1. Fresh manure production and characteristics

Item	Units <sup>b</sup>	Animal type <sup>a</sup>			
		Dairy	Beef	Sheep	Horse
kg (1,000 kg/d)					
Total manure <sup>c</sup>	Mean <sup>d</sup>	86	58	40	51
	SD	17	17	11	7.2
Urine	Mean	26	18	39	10
	SD	4.3	4.2	4.8	0.74
Total solids	Mean	12	8.5	11	15
	SD	2.7	2.6	3.5	4.4
Biochemical oxygen demand, 5-d	Mean	1.6	1.6	3.1	1.7
	SD	0.48	0.75	0.72	0.23
Chemical oxygen demand	Mean	11	7.8	11	NA <sup>d</sup>
	SD	2.4	2.7	2.5	NA
Total Kjeldahl nitrogen <sup>e</sup>	Mean	0.45	0.34	0.42	0.30
	SD	0.096	0.073	0.11	0.063
Ammonia nitrogen	Mean	0.079	0.086	NA	NA
	SD	0.083	0.052	NA	NA
Total phosphorus	Mean	0.094	0.092	0.087	0.071
	SD	0.024	0.027	0.030	0.026
Orthophosphorus	Mean	0.061	0.030	0.032	0.019
	SD	0.0058	NA	0.014	0.0071
Potassium	Mean	0.29	0.21	0.32	0.25
	SD	0.094	0.061	0.11	0.091
Total coliforms <sup>f</sup>	Mean	1,100	63	20	490
	SD	2800	59	26	490
Fecal coliforms <sup>f</sup>	Mean	16	28	45	0.092
	SD	28	27	27	0.029
Fecal streptococci <sup>f</sup>	Mean	92	31	62	58
	SD	140	45	73	59

<sup>a</sup>Differences within species according to usage exist, but sufficient fresh manure data to list these differences were not found. Typical live animal masses for which manure values represent are dairy, 640 kg; beef, 360 kg; sheep, 27 kg; horse, 450 kg (ASAE, 2003).

<sup>b</sup>All values are expressed on wet basis.

<sup>c</sup>Feces and urine as voided.

<sup>d</sup>Mean estimates within each animal species are comprised of varying populations of data. Maximum numbers of data points for each species are: dairy, 85; beef, 50; sheep, 39; horse, 31. NA = data not found.

<sup>e</sup>All nutrients values are given in elemental form.

<sup>f</sup>Mean bacteria colonies per 1,000 kg of animal mass multiplied by 10<sup>10</sup> colonies per 1,000-kg animal/mass divided by kg of total manure per 1,000 kg of animal mass multiplied by density (kg/m<sup>3</sup>) equals colonies per m<sup>3</sup> of manure.

(Table 1). Average amounts of N (kg, wet basis) in manures range from 0.30 kg for horses to 0.45 kg for dairy cattle (Table 1). For P, the range is from 0.071 kg for horses to 0.094 kg for dairy cattle. At both field and watershed scales, grazing animals hence serve as a significant source for nutrients and organic matter.

### Environmental Benefits of Forage Production and Grazing Animals

The soil improvement characteristics of grasslands have long been recognized (Ball et al., 2002). After land has been devoted to perennial forages for several years, the trend is for subsequent arable crops to produce better than would otherwise have been the case. The deep root penetration of many forage crops into compacted soil layers can leave channels that improve water and air movement and enhance root penetration of subsequent crops. Perennial grasslands also tend to make the soil more suitable for subsequent arable crops in other ways, including improving soil tilth due to the

activity of earthworms, soil insects, and microorganisms. Over time, the nutrient-holding capacity of the soil increases and various mineral cycles operate to increase nutrient availability in the surface layer.

Compared with other agricultural land uses, growing forage crops greatly decreases erosion. Perennial grass sods are particularly effective in reducing soil erosion losses. Ball et al. (2002) concluded that if the percentage of cropland devoted to forage crops were substantially increased, there would be a considerable improvement in overall water quality. When livestock are produced on pasture and the land is not overgrazed, the likelihood of nutrient contamination of water may be much lower than that of heavily fertilized conventionally produced crops. When land has a thick cover of perennial forages, there is little runoff and therefore less chance for fertilizers to be washed away. Most forage crops, especially perennial grasses, form dense root systems that effectively serve as filters to remove contaminants before they can seep into the groundwater.



Organic components of feces and urine from grazing animals can build soil organic matter reserves, resulting in soils having increased water-holding capacity, increased water-infiltration rates, and improved structural stability. These changes can decrease soil loss by wind and water erosion. Soil applied manures decrease energy needed for tillage and reduce impedance to seedling emergence and root penetration (Wright, 1998). Manures stimulate the growth of beneficial soil microbial populations, increase microbial activity within the soil, and increase the population of beneficial mesofauna, such as earthworms.

### Environmental Problems Associated with Grazing Animals

#### Sediment

Water quality of streams, lakes, or other water bodies may be degraded by excessive amounts of dissolved or suspended sediment in surface runoff or base flows. Numerous studies have reported sediment concentrations and loads for a variety of drainage systems (Long and Bowie, 1963; McGuinness et al., 1971; Griffiths, 1982; Neff, 1982; Carling, 1983), along with information relating loads to rainfall intensity and duration, runoff amount, drainage area, or land use (Dragoun and Miller, 1966; Dendy and Bolton, 1976; Costa, 1977; Ostry, 1982). Heavy loads of suspended sediment in streamflow can reflect erosion from grazed pastures with poor forage stands and heavy traffic from grazing animals.

It has been recognized that for over 90 yr, heavy, continuous grazing accelerates erosion and runoff (Rich, 1911; Duce, 1918; Sampson and Weyl, 1918). The literature is filled with examples of the adverse impacts of overgrazing on watersheds (Dunford and Weitzman, 1955; Ellison, 1960; Smeins, 1975; Dregne, 1978; Crouch, 1979). Love (1958) wrote, "There is a large body of information leading to the conclusion that heavy grazing has had bad hydrologic consequences." It is doubtful that more investigations are needed to emphasize this conclusion.

#### Nitrogen

The compound form of N of primary concern is  $\text{NO}_3$  nitrogen. Nitrate movement into surface and ground waters is of concern both for health and environmental quality reasons (Galloway et al., 2003). Nitrate concentrations in excess of 10 mg/L cause methemoglobinemia, which is toxic to infants (Federal Register, 1975). Most cases of methemoglobinemia occur after consuming water with high concentrations of  $\text{NO}_3$  nitrogen. Infants are particularly susceptible, as are people who receive kidney dialysis treatment (Follett and Follett, 2001). In the United States,  $\text{NO}_3$  nitrogen concentrations exceed this level in more than 15% of groundwater samples from four of the 33 major regional aquifers

most commonly used as sources of drinking water (Nolan and Stoner, 2000). Other effects associated with elevated concentrations of  $\text{NO}_3$  nitrogen in drinking water include respiratory infection, alteration of thyroid metabolism, and cancers induced by conversion of  $\text{NO}_3$  nitrogen to N-nitroso compounds in the body (Follett and Follett, 2001). Eutrophication of lakes or other water bodies occurs when excess plant or algal growth takes place. Nitrogen may be a limiting nutrient to growth of these species, and hence excess  $\text{NO}_3$  nitrogen levels entering streams or lakes with surface runoff or by shallow subsurface flow may cause environmental quality problems.

Nitrogen exists in soil as  $\text{NO}_2$ ,  $\text{NO}_3$ , or  $\text{NH}_4$  nitrogen, or in organic forms within the soil organic matter fraction. Nitrate ions are repelled by the clay particles in the soil and generally are not absorbed within the soil matrix. Hence, as water moves through the soil,  $\text{NO}_3$  nitrogen generally moves freely with the water. The actual movement of  $\text{NO}_3$  nitrogen through soil lags behind the wetting front due to mixing processes such as diffusion and hydrodynamic dispersion, which occur between the resident soil solution and the infiltrating water from irrigation or rainfall. Numerous studies have documented  $\text{NO}_3$  nitrogen concentrations greater than 10 mg/L in groundwater associated with agricultural activities including cropping enterprises, livestock, and grazing (Spalding and Exner, 1980; Hubbard et al., 1986, 1987; Naney et al., 1987; Sharpley et al., 1987; Hubbard and Sheridan, 1989, 1994). Nitrate contamination of groundwater can also occur in urban areas from septic tanks or over fertilization of lawns (Hubbard and Sheridan, 1994).

Nitrogen from the urine and feces of grazing animals can negatively affect water quality when the number of grazing animals per land area exceeds the N fertility needs of the forages. Campbell et al. (1977) compared standard beef cattle pasture stocking rate, double pasture stocking rate (cattle were supplemented with silage when necessary), confinement, and a natural area and found that  $\text{NO}_3$  nitrogen concentrations in shallow groundwater wells at 1.2 m increased at the double stocking rate compared with the other treatments. A water quality problem can also occur when the sum of N from the inorganic fertilizers applied to produce quality forages plus N from the grazing animals exceeds N uptake by the forages. An example of such a problem is shown in Table 2 from Hubbard et al. (1987). This table shows  $\text{NO}_3$  nitrogen concentrations in shallow groundwater from a study where dairy lagoon wastewater was applied by center pivot at two different wastewater application rates (496 or 1,018 kg of  $\text{N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ ). A control area received N fertilizer at recommended rates (491 of  $\text{N} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ ) for production of coastal bermudagrass (*Cynodon dactylon* L.). All of the areas were grazed by cattle during the winter months. Table 2 shows that the highest  $\text{NO}_3$  nitrogen concentrations in the shallow groundwater at a depth of 3.6 m were found under the control area. Although the control

**Table 2.** Mean NO<sub>3</sub> N concentrations in shallow groundwater by depth and treatment at dairy lagoon wastewater application site

Treatment	Depth, m		
	1.2	2.4	3.6
Wastewater			
Low N rate, 496 kg of N·ha <sup>-1</sup> ·yr <sup>-1</sup>	45 <sup>ax</sup>	36 <sup>ay</sup>	16 <sup>bz</sup>
High N rate, 1018 kg of N·ha <sup>-1</sup> ·yr <sup>-1</sup>	42 <sup>ax</sup>	28 <sup>by</sup>	16 <sup>bz</sup>
Control			
Inorganic N at recommended rates, 491 kg of N·ha <sup>-1</sup> ·yr <sup>-1</sup>	34 <sup>bx</sup>	28 <sup>bx</sup>	31 <sup>ax</sup>

<sup>a,b</sup>Means within depths with different superscripts differ ( $P < 0.05$ ) according to a LSD test.

<sup>x,y,z</sup>Means within treatments with different superscripts differ ( $P < 0.05$ ) according to a LSD test Hubbard et al. (1987).

area was selected with the initial hypothesis that it would have low NO<sub>3</sub> nitrogen concentrations in shallow groundwater compared with areas receiving dairy lagoon wastewater (because it received less applied N and did not have wastewater applied daily), in reality, the inorganic N applications at recommended rates for quality forage production plus waste from the grazing animals resulted in higher NO<sub>3</sub> nitrogen concentrations in the shallow groundwater at 3.6 m under the control area, than those found under the areas receiving lagoon wastewater. This finding of worse groundwater quality for NO<sub>3</sub> nitrogen under forage production with grazing compared with high loadings of liquid animal wastes shows that it cannot be assumed that grazing and forage systems will enhance water quality. Without careful consideration of total N applications from the grazing and forage production system, NO<sub>3</sub> nitrogen contamination of shallow ground water can occur.

### Phosphorus

Phosphorus is of environmental concern because excess amounts in surface water bodies may cause eutrophication. Phosphate is a soluble agricultural chemical that may be moved from point of application by surface runoff or move out of the soil surface layer with percolation. In general, PO<sub>4</sub> is considered to be of concern primarily for surface runoff since it binds to Fe, Al, or Ca in the soil depending on pH and is not readily leachable. Soluble PO<sub>4</sub> and PO<sub>4</sub> associated with sediment in surface runoff have been found to vary linearly with P application rate (Romkens and Nelson, 1974). Low concentrations of dissolved PO<sub>4</sub> have been found in runoff from deep incorporation of fertilizers (Holt et al., 1970). Movement of PO<sub>4</sub> through the soil profile varies with soil texture. For nonsandy soils, the leaching of PO<sub>4</sub> with percolating water is extremely low or undetectable. The PO<sub>4</sub> content of percolate from nonsandy soils can be within an order of magnitude of 0.1 mg/L (Russell, 1961). Numerous investigators (Spencer, 1957; Hingston, 1959; Russell, 1960; Bolton and Coulter, 1996), however, have shown that in very sandy soils, PO<sub>4</sub> will move down the profile to a considerable depth (>1.0 m). On the basis of diffusion studies, Olsen

and Watanabe (1970) concluded that there was an eight-times-greater risk of PO<sub>4</sub> pollution of ground water from sands than from clays.

The contribution of P from animal wastes can under some circumstances represent a significant fraction of the P circulating in agricultural systems. Where fecal matter is deposited into farm ponds or streams the direct effect may be noticeable. Most severe P problems related to animal wastes may arise where there are local, high density animal populations in feedlots, barnyards, or pastures close to streams (Schepers and Francis, 1982; Schepers et al., 1982; Fisher et al., 2000). Actual losses will depend upon management practices. Chichester et al. (1979) showed that concentrations of P in runoff were not increased by summer grazing of pasture in Ohio, but where animals were pastured throughout the year, winter damage to the soil surface (trampling from hooves damaging vegetation and causing soil compaction) caused both increased runoff and nutrient discharge.

### Pathogens

Water quality in many lakes and rivers has been impaired by the presence of high levels of fecal coliform bacteria, which is indicative of contamination by feces (Jones and Roworth, 1996; Ackman et al., 1997). Such contamination brings the threat of infection for people who use the water for drinking, bathing, or watering fruits and vegetables. Underlying this concern are numerous reports of waterborne outbreaks of disease involving fecal organisms such as *Escherichia coli* O157:H7, *Campylobacter jejuni*, *Salmonella* species, *Vibrio cholerae*, and shigellae (Jones and Roworth, 1996; Gughani, 1999; Licence et al., 2001). Other bacterial infections that can be transmitted in water from animal to animal and from animal to human include *Listeria*, *Leptospira*, *Brucella*, *Coxiella*, and *Mycoplasma* (Hensler et al. 1970; Young 1974; Hatfield et al., 1998). Nonbacterial infectious agents that can be transmitted in water include fungi and protozoa (*Cryptosporidium*). Managers of modern manure management systems, including grazing, must take into account the possibility of disease transmission through



the environment and must therefore try to prevent manure-laden runoff from reaching water bodies. It is also important to determine whether the source of fecal contamination is of human, livestock, or wildlife origin, as microorganisms of human origin are regarded as having greater potential to cause disease in humans (Puech et al., 2001).

Recent interest in this area has focused on *Cryptosporidium parvum*, a widespread protozoan parasite afflicting animals and humans (Wright, 1998). The dominant mode of transmission of *C. parvum* to humans is believed to be via contaminated drinking water and recreational waters. Zoonosis is the term used to describe infections crossing hosts, such as the case with *C. parvum*. Although no clear-cut epidemiological cause and effect has been established, it is widely believed that farm animals are the predominant source of *C. parvum*. Dairy farms are particularly suspect as potential sources of *C. parvum* because newborn calves are readily infected and excrete large numbers of the infectious stage (oocyst) of this organism (Wright, 1998).

### Oxygen-Demanding Materials

Manure from grazing animals contains organic matter, which can serve as oxygen-demanding materials (Hatfield et al., 1998). Organic matter serves as an energy source for aerobic bacteria in a receiving stream or lake. Increased bacterial metabolism resulting from a discharge of organic waste into a water body increases the oxygen depletion rate of the water. If the rate of oxygen depletion exceeds the aeration rate of the stream, oxygen depletion occurs. Decreased or depleted oxygen levels can result in fish kills and anaerobic conditions in the stream or other water body.

Organic matter in contaminated waters has historically been measured as biochemical oxygen demand (BOD). This is a measure of the amount of oxygen required to metabolize waste during a specified time, usually 5 d (Hatfield et al., 1998). Another measure of organic strength of a waste is chemical oxygen demand (COD), which is based on chemical rather than biological oxidation. Chemical oxygen demand will exceed the BOD demand value for animal wastes, since animal manure and other waste products contain organic materials resistant to aerobic bacterial degradation. Chemical oxygen demand/BOD demand ratios vary from 3.5 to 6.5 depending on species and feed rations (Hatfield et al., 1998). The ASAE standards (2003) show COD ranging from 7.8 to 11 kg and biochemical oxygen demand ranging from 1.6 to 3.1 kg (Table 1).

### Importance of Landscape Scale in Evaluating Potential Water Quality Effects of Grazing Animals

Concerns with grazing animals relate primarily to animal density and quality of forage stand. Assuming a good forage stand with protection of the soil surface

against erosion, there are few environmental concerns at low grazing animal density. Concerns at low animal density primarily relate to the animals having free access to water bodies in which they can deposit urine and manure, and the accompanying problems with N, P, pathogens, and organic matter, which affect biochemical oxygen demand and chemical oxygen demand. Common good grazing management practices at both low and medium animal densities that alleviate nutrient and pathogen management issues include rotational grazing, portable water supply, portable shade source, and fencing animals from water bodies.

Most environmental concerns with grazing animals occur at high animal densities. With high animal densities, forages may be overgrazed, trodden, and significant soil erosion may occur. Pluhar et al. (1987) compared selected grazing treatments in the Texas Rolling Plains and showed that grazing caused a significant decline in infiltration rates and a significant increase in sediment production as compared to an ungrazed enclosure. High animal densities result in large amounts of urine and feces deposited in relatively small areas and increased probabilities for nutrients and pathogens to move with surface runoff or enter groundwater. Urine and feces from grazing animals are deposited at separate times and in different areas of the pasture. Grazing animals avoid feces piles and surrounding vegetation due to odor at first, and then to maturity of the vegetation afterwards. Grazing animals also tend to congregate in shady areas or around water supplies, which means that there are localized areas within pastures with much greater trampling damage and loads of urine and feces.

Landscape scale is an important consideration when evaluating the potential environmental impacts on water quality associated with grazing animals. At the individual pasture or field scale, consideration is primarily related to maintaining a good forage stand, having the proper numbers of animals per land area, and fencing animals out of streams and other water bodies. At the large landscape or watershed scale, grazing animal densities and proximity of operations to streams, rivers, and lakes are important. An example of a gauged watershed where hydrologic flow is measured and water samples are collected for sediment, N, P, and pathogen analyses is shown in Figure 1. This is the Little River Watershed, as gauged by the Southeast Watershed Research Laboratory, Tifton, GA. The watershed is 334 km<sup>2</sup> in area and is gauged in a nested design from the smallest subwatersheds (K, J) in the upper part of the Little River Watershed to Station B, which gauges the entire 334 km<sup>2</sup>. This watershed has relatively few grazing animals. However, the size and nested design of this gauged watershed illustrate the scale at which the impact of grazing animals on water quality should be evaluated.

Although individual pastures with grazing animals may not appear to be causing water quality problems if there is no obvious erosion and the animals are fenced

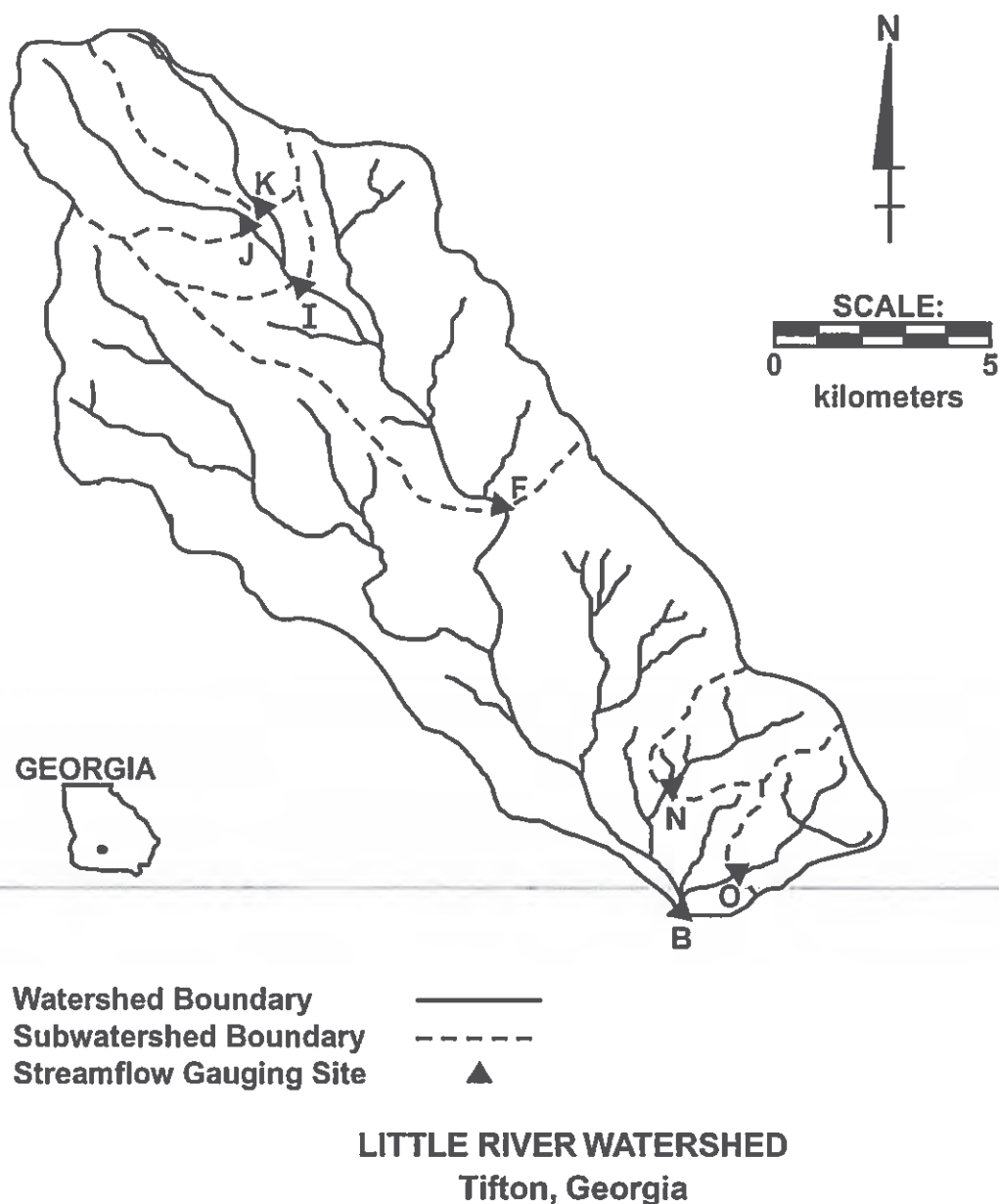


Figure 1. Schematic of Little River Watershed with subwatershed boundaries and streamflow gauging sites (Tifton, GA).

out of the streams and riparian zones, the true impact of animal production systems (including grazing) is determined by measurements at a larger landscape or watershed scale. The overall impact of grazing animals is the sum of the total animals at the large scale, how they are distributed over the watershed, and management practices within each operation. Water quality problems associated with grazing animals tend to be most serious when the total number of animals in a landscape or watershed significantly exceeds the carrying capacity of the land, poor management practices are used, and when animal operations are in the lower part of the landscape. Assessment of overall impact of animal production at the landscape scale must also

consider confined animal production operations. These operations in general pose a much greater risk to soil and water quality at both the local and landscape scale than do grazing operations.

#### Riparian Buffer Systems

One landscape management tool that has been found to be effective in reducing water pollution from both cropland and grazed areas in the humid eastern part of the United States is use of riparian buffer systems. Many studies at different sites in the Gulf Atlantic Coastal Plain region have shown that concentrations and loads of N in surface runoff and subsurface flow

## PHYSICAL CHARACTERIZATION OF THE RIPARIAN BUFFER

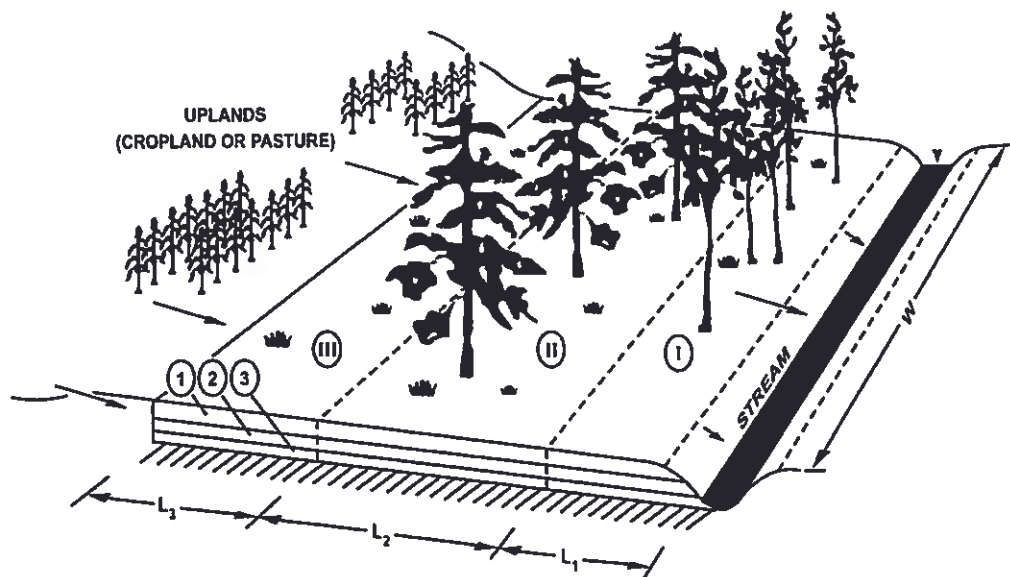


Figure 2. Schematic of three zone riparian buffer system. Zone III is grass; Zone II represents managed trees that are periodically harvested; Zone I shows hardwood trees that protect the stream bank.

are markedly reduced after passage through a riparian forest (Lowrance et al., 1983, 1984; Peterjohn and Correll, 1984; Jacobs and Gilliam 1985; Hubbard et al., 1996). The limited field data on using riparian forests to control agricultural nonpoint source pollution has been integrated into draft national specifications for riparian buffer systems by the USDA-Natural Resources Conservation Service and Forest Service. These draft specifications provide for a riparian buffer system of three zones (Figure 2). Zone 1 is a narrow band of permanent trees (5 to 10 m wide) immediately adjacent to the stream channel, which provides streambank stabilization, organic debris input to streams, and shading of streams. Zone 2 is a forest management zone where maximum biomass production is stressed, within limits placed by economic goals. Zone 2 may be harvested on appropriate rotations (20 to 60 yr). Zone 3 is a grass buffer strip up to 10 m wide used to provide control of coarse sediment and spreading of overland flow. In drier portions of the United States, where tree growth is difficult, buffers of grasses have been advocated. However, recent work by Hubbard et al. (2003) indicates that grasses alone are not as effective in assimilating nutrients as combined grass-riparian forest buffers.

On January 15, 2003, the U.S. Environmental Protection Agency adopted new Federal rules governing animal feeding operations (<http://cfpub.epa.gov/npdes/index.cfm>). All states must now adopt new rules that are at least as stringent as these new federal rules. The new rules require 30.4 m setbacks from surface water or 10.6 m vegetated buffers on all large animal feeding operations. Although these rules are specific to confined animal feeding operations rather than grazing animals,

inclusion of riparian buffers into grazing of pastures is recommended.

### Implications

Forage production and grazing animal systems can both positively and negatively affect water quality. Compared with cropland, forage systems protect the soil surface from erosion, and, if fertilizer and animal waste inputs are low to moderate, both surface and ground water quality under grazed areas may be better than that under cropped areas. The water quality contaminants of concern from grazing systems are sediment (erosion), N, P, pathogens, and organic matter. Grazing animals negatively affect water quality when the number of animals exceeds the carrying capacity of the land (at both the pasture and watershed scales). Forage production may have negative effects on water quality when fertilizer plus animal waste inputs exceed crop nutrient needs, or when forage quality is poor and soil erosion can occur. Grazing animal systems should be managed to include adequate land area for animal numbers at the field and landscape scale, fencing animals out of streams and lakes, and use of riparian buffer systems to assimilate sediment, nutrients, and pathogens from grazing animals.

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## LIVESTOCK GRAZING EFFECTS ON PHOSPHORUS CYCLING IN WATERSHEDS

GLENN E. SHEWMAKER, Northwest Irrigation & Soils Research Laboratory, USDA-ARS, 3793 N. 3600 E., Kimberly, ID 83341, Phone: (208) 423-6515, Fax: (208) 423-6555, E-mail: shew@kimberly.ars.pn.usbr.gov

### ABSTRACT

Elevated phosphorus (P) loading of wetlands, streams, lakes, and reservoirs can occur from nonpoint sources such as grazing of uplands, wet meadows, and palustrine wetlands. Erosion caused by livestock grazing or any activity will increase the total P load in streams; however, herbivores can also harvest P from forage and export a significant amount of P from the watershed. Some land managers fail to recognize that the P taken up by plants will continue to cycle through soil and water. Dissolved P or P attached to soil particles suspended in water are the primary vectors of P movement in a watershed. Herbivores add another vector with more opportunities to export P from the watershed. Using best management practices such as rotational grazing, buffer strips next to wetlands, and proper irrigation management should reduce overland flow and streambank erosion. Livestock grazing should harvest and remove a significant amount of P from the ecosystem by incorporation into bone and tissue mass of growing animals and beef export from the basin. The Phosphorus Uptake and Removal from Grazed Ecosystem (PURGE) model uses three separate methods to estimate P retention in cattle, and using limits of the input variables, predicted a range from 4 to 50 Mg P could be removed annually from 17,700 ha of pasture in the Cascade Reservoir watershed in west-central Idaho. With proper grazing management, cattle should be part of a long-term solution to P loading and improvement of water quality in Cascade Reservoir.

Key words: Phosphorus, phosphorus cycling, phosphorus export, livestock grazing effects, model, nutrient

Livestock grazing on public and private lands is increasingly scrutinized for its contribution to nutrient loading of water bodies. While improvements in grazing management usually can reduce nutrient loading, P-loading due to grazing may be overestimated and goals for reduction of nutrient loading may be unrealistic. An understanding of the magnitudes and flows of P within the soil, plant, animal, and microbial pools is essential if land managers are to limit P loading in surface water.

### EUTROPHICATION AND NONPOINT SOURCES OF P

The process of water bodies becoming rich in nutrients with the result of abundant microbial growth is called eutrophication. Microbial growth in fresh water systems is often limited by available P. The eutrophication process can remove oxygen from waters, resulting in the death of desirable aquatic species.

Nonpoint sources may contribute 60% of the P load to reservoirs (Valley Soil Conservation District 1991). But

often "natural" or background levels prior to grazing or disturbance by man are unknown. Phosphorus load in a stream is a function of geologic materials, soils, topography, vegetative cover, precipitation intensity, and water hydraulics. The contribution of P from natural sources can be difficult to differentiate from anthropogenic sources. Abrams and Jarrell (1995) found that high native P levels and P adsorption characteristics of soils in a tributary watershed of the Willamette River were an important nonpoint source of P. Determining background levels is difficult but critical to setting realistic goals for nutrient loading and its reduction.

### NUTRIENT CYCLING

Transport of P by overland flow depends on desorption, dissolution, and extraction of P from soil, and mineralization of plant material and feces. Temperature, precipitation, anaerobic soil conditions, and evapotranspiration rates further influence the process. Plant species composition and rate of decay affect the P leached from plant material. Soil P loss is dependent on

the capacity of reactive mineral and organic matter surfaces, pH, and concentrations and interactions of other elements (Broberg and Pearson 1988).

Climate is the overriding variable in nutrient loading. Separating climatic effects from any treatment of the watershed is difficult. Thus, it may be inaccurate to infer trends of P loading without accounting for yearly variation in weather effects and stream flows.

In a system without herbivores, nutrients cycle from soil to soil water, to plants, to litter, and back to soil (Fig. 1). Erosion of soil or leaching through the groundwater transports P to streams and reservoirs. When herbivores are added to the ecosystem, P may be found in more chemical forms with varying solubility. Urine and feces return unabsorbed or unretained P to the soil surface to continue cycling. Also, soluble P from plant leachate can move in overland flow into streams and reservoirs.

## RESEARCH DESIGNS

Monitoring studies may be an inappropriate basis from which to infer the effects of grazing management on P loadings. For example, the comparison of one grazed watershed with an ungrazed watershed may have confounded effects with no measure of experimental error. One confounded effect is the watershed itself may be a larger source of variation than treatment; i.e., different soils, aspects, slopes, vegetative cover, etc. In another case, the comparison of P concentration above and below grazed and nongrazed pastures may be confounded by stream and soil differences. Monitoring studies are only useful in recording what happened, not why it happened. Critical studies are needed that test hypotheses of cause and effect in addition to monitoring.

Thus, objectives of this study are to review the literature on P cycling, present the relative masses of P in ecosystem components, describe a simulation model to predict P export in bodies of grazing cattle, discuss best management practices (BMPs) to limit P loading, and propose research to solve nonpoint source P loading.

## METHODS

### STUDY AREA

This conceptual experiment utilized data from Valley Soil Conservation District (1991) and Division of Environmental Quality (1995) as a case study of the Cascade Watershed in west-central Idaho. The watershed is 1,580 km<sup>2</sup> with elevations from 1,470 to 2,740 m. The mountains surrounding Long Valley are mostly Idaho Batholith except for West Mountain, which is Columbia River Basalt. The valley was formed by a down-dropped fault block which has been filled with glacial debris and alluvial material. Soils have little development.

The average annual precipitation at the city of Cascade is 554 mm and may exceed 1,270 mm at the higher elevations. Most of the precipitation occurs as snow and reaches a maximum depth of 0.3 to 1 m on the valley floor and generally exceeds 2.4 m in the higher mountains during April. The predicted average water available for runoff is 193 mm for a 15-day period (Valley Soil Conservation District 1991). Thus surface runoff would be about 140 mm. Much of the P enters wetlands as a pulse during snow melt. The land use of interest is the 17,800 ha of pastureland, 11% of the watershed.

Eutrophication of Cascade Reservoir is attributed to excess P and other nutrients entering the shallow reservoir through tributaries and irrigation return flows (Entranco Engineers 1991). Estimated sources of P (Division of Environmental Quality 1995) are agriculture (30%), forest (22%), internal recycling (19%), the McCall sewage treatment plant (11%), urban/recreation (8%), rainfall/dryfall (7%), fish hatchery (2%), waterfowl (1%), and on-site wastewater (<1%). Watershed nonpoint sources may contribute 60% of the P load (Valley Soil Conservation District 1991).

### MODEL DEVELOPMENT

The Phosphorus Uptake and Removal from Grazed Ecosystems (PURGE) simulation model was developed to estimate P uptake by grass and P retention in bodies of grazing cattle (Shewmaker 1997). Input variables include known, approximate, and assumed values based on measurements, scientific literature, and personal experience. The model does not simulate water flow, soil erosion, or nutrient movement, except by means of ruminant animals. Three methods within the model estimate P exported in cattle tissue.

Method #1 uses net P absorption by animals, daily dry matter (DM) consumption, cattle weight, P concentration in grass, stocking rate, and area grazed as the input variables. These values are multiplied as linear combinations to calculate carrying capacity, total weight gain, grass consumed, P consumed, P retained, and P removed with cattle. Values for net P adsorption are assumed based on Agricultural Research Council (1980) and Miller (1979). The P concentration in grass is assumed to be from 0.18 to 0.30 % reported by Kincaid (1993), Follett and Wilkinson (1995), and data from our lab.

Method #2 uses forage production (Valley Soil Conservation District 1991), P concentration in grass (from Method #1), and the ratio of P removed per plant uptake (Cohen 1980) as input variables. These values are multiplied in linear combinations to calculate P removed by cattle on an area basis and total P removed from the area grazed.

Method #3 was suggested by R.C. Bull, animal scientist at the University of Idaho (personal communica-



tion 1996). The P composition of bone and soft tissues in cattle is highly predictable and therefore P export is easily calculated from cattle weight gain while on the pastures. The P content of wet bone tissue is 4.5% (Church 1971), and 80% of total body P is found in the skeleton and teeth. The acreage and weight gains used are those described in Method #1. Based on these assumptions, the values are multiplied to calculate weight gain as bone, bone P, and non-bone P from animal gain. The P in bone growth and non-bone P is added to calculate total P from animal mass gain.

## RESULTS

### THE SOIL POOL

Soil P is the largest pool by far; however, much of this P is not immediately available. Soils in the Pacific Northwest plus most of Nevada, Utah, and Wyoming generally contain from 0.2 to 0.3 % total phosphate ( $P_2O_5$ ) in the surface foot of soil (Tisdale et al. 1993). Organic forms of P usually decrease with depth, vary from 15 to 80%, and average 50% of total soil P. If a soil contains 4% organic matter in the surface 15 cm, the organic P content (assuming P is 1% of the organic matter) is (Tisdale et al. 1993):

$2.24 \times 10^4 \text{ kg soil/ha} \times 15 \text{ cm} \times 0.01 \times 0.04 = 896 \text{ kg organic P/ha to 15 cm}$

Soil P may be immobilized to organic forms or chemically fixed inorganic P. Organic P must be mineralized to the inorganic form to be taken up by plants. Inorganic P in solution which is not absorbed by plants or immobilized by microorganisms can be adsorbed to mineral surfaces (labile P) or precipitated as secondary P compounds. Soil pH has a large effect on P fixation or retention. In acid soils, P precipitates as Fe/Al secondary minerals or is strongly sorbed to clay and metal oxide surfaces. In calcareous soils (pH 8), P precipitates as Ca-P secondary minerals or is adsorbed to  $CaCO_3$  (Tisdale et al. 1993). Precipitation reactions will occur when the concentration of P and associated cations in the soil solution exceeds the solubility product of the mineral.

Flooding generally increases available P due to conversion of  $Fe^{3+}$  phosphates to more soluble  $Fe^{2+}$  phosphates and hydrolysis of Al phosphate (Tisdale et al. 1993). Flooding or saturated soil moisture provide anaerobic conditions needed for the microbial population to reduce the  $Fe^{3+}$ . This process also generally occurs at pH near neutral.

### THE PLANT POOL

The plant pool contains the next largest P source. Phosphorus concentrations in forages may range from 0.14% to over 0.30% P (Follett and Wilkinson 1995). Inorganic P ( $H_2PO_4^-$  or  $HPO_4^{2-}$ ) is taken up by plant roots

and most is converted to organic forms upon entry into the root or after it has been transported through the xylem.

What happens to P in plants as plants die or become senescent? Leaves, stems, and roots decompose by weathering and microbial assimilation of nutrients. Nutrients are recycled to the soil by mineralization, where they remain until absorbed by plants or leached from the soil into water bodies. While P losses from live plants are small, 69-80% of total P may be leached from plant residue (Harley et al. 1951; Timmons et al. 1970; c.f. Mays et al. 1980). Much water-soluble P is assimilated by microbial activity and converted back into organic forms. Precipitation intensity and duration, the time between plant dormancy or senescence and the first precipitation, affect the P returned to the soil or lost in runoff (Mays et al. 1980).

### THE WATER POOL

Elevated phosphorus (P) loading of wetlands, streams, lakes, and reservoirs can occur from nonpoint sources such as grazed uplands, wet meadows, seasonally flooded, and saturated wetlands. Erosion caused by livestock grazing or any activity will increase total P load in streams.

The Environmental Protection Agency (1989) recommends total P not exceed 0.05 mg/L for a stream at the point where it enters a lake or reservoir, 0.025 mg/L for reservoirs, and 0.10 mg/L for free-flowing rivers. The total P in 1-m depth of reservoir or lake surface water would contain 0.25 kg total P/ha if the concentration was at the Environmental Protection Agency recommended limit. The average total P concentration in Cascade Reservoir ranged from 0.019 to 0.031 mg/L in 1974 (Division of Environmental Quality 1995). Reservoir concentrations ranged from 0.018 to 0.102 mg/L during the period 1978 through 1982 (Zimmer 1983).

Direct rainfall contributed an estimated 0.175 kg P/ha lake surface for water years 1975 and 1981 (Environmental Protection Agency 1977). An assumed value of 0.05 mg P/L multiplied by rainfall volume was used by Division of Environmental Quality (1995) to estimate P content of rainfall when actual measurements are not available. Internal recycling may contribute 19% of the P load in the reservoir (Division of Environmental Quality 1995).

### THE ANIMAL POOL

Phosphorus mass in the animal pool will be less than the plant pool (Table 1) if P is not imported as feed supplement. Grazing livestock utilize the forage plant material and recycle most nutrients back into the system. Herbivores add another vector with more opportunities to export P from the watershed (Fig. 1). The net P absorption by cattle is about 90% efficient in young calves and 55% efficient in cows. Bone tissue contains 4 to 4.5% P

Table 1. Hypothetical effects of forage utilization by cattle on recycling of P from plant residue or animal excreta.

Forage Utilization	Soil	Surface Water to 1 m	Plant uptake	Litter return	Animal product	Feces return	Stocking density
%			kg P/ha				head/ha
0	1875	0.25	15	15.0	0.0	0.0	0.00
25	1875	0.25	15	11.3	0.4	3.4	0.17
50	1875	0.25	15	7.5	1.5	6.0	0.33
75	1875	0.25	15	3.8	3.4	7.9	0.50
100	1875	0.25	15	0.0	6.0	9.0	0.67

Assumptions: The P concentration in the surface 15 cm of soil averages 0.1% P. The bulk density is 1.25 Mg/m<sup>3</sup>. The surface water to a 1 m depth averages 25 ug/L. Net primary production is 6,000 kg of dry herbage/ha containing 0.25% P. The retention of P in the cattle is 60%. It requires 9,000 kg/ha to be consumed to produce a 400-kg calf containing 2.66 kg of P. Therefore, at a herbage utilization efficiency of 25%, 6 ha will be required; at a utilization efficiency of 75% only 2 ha is required. (After Mays et al. 1980) Fresh bone contains 4.5% P, bone P accounts for 80% of total body P, and bone growth is about 20% of the animal growth (Church 1971).

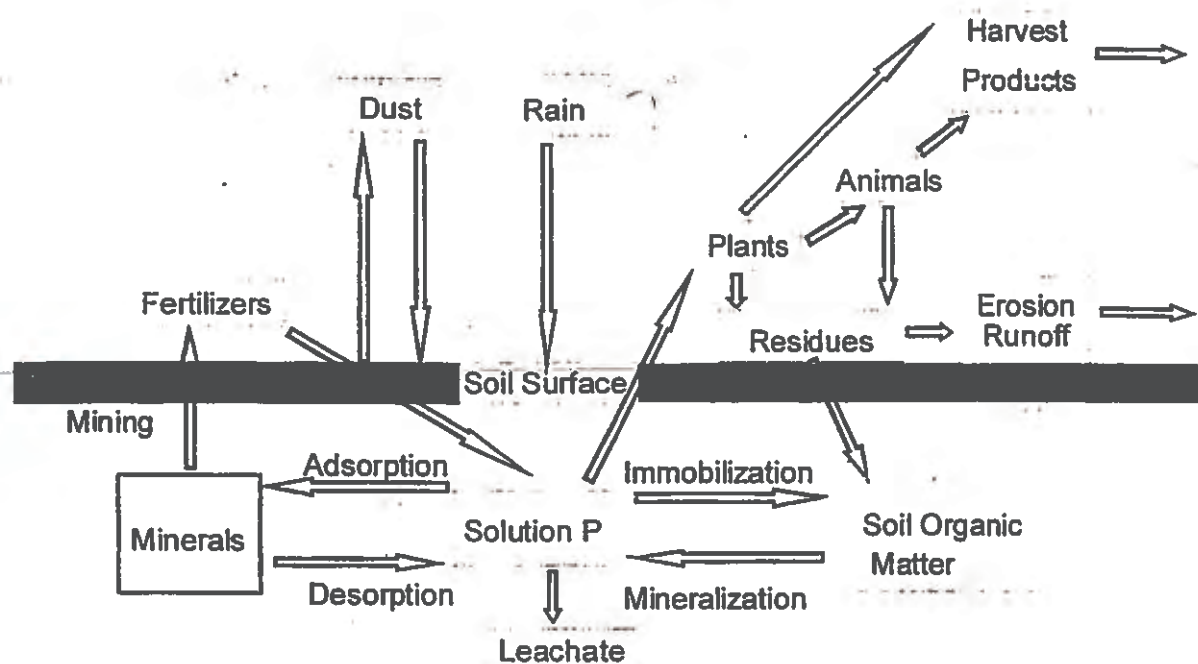


Figure 1. The P cycle on a grazed pasture.

(Church 1971), and from 75 to 80% of total body P is found in the skeleton and teeth. Phosphorus uptake in cattle with daily gains of 0.5, 0.75, and 1 kg/head would be 0.2, 0.88, and 2.16 kg/ha, respectively, during the grazing season (see Method #2, Table 2).

Phosphorus in the diet of grazing animals which is not retained is excreted primarily in the feces. About 0.06 g of organic P is excreted per 100 g of feed eaten (Barrow 1975). Sheep feces retained 40% of the initial total P after 2 years of exposure to weathering and 100 cm of rain (Bromfield & Jones 1970), and 90% of the residual P was

in the organic form. Floate (1970a,b,c,d) concluded that organic P in both plant and animal residues appeared to be more of a sink than a source of P cycling.

#### LIVESTOCK GRAZING EFFECTS ON P CYCLING

A simplistic P budget on grazing land is represented in Table 1. The magnitude of P in plant litter decreases linearly as herbage utilization increases, and the magnitude of P in animal product and dung increases linearly. All of the plant P is recycled unless removed by harvesting

Table 2. Simulations of P export produced by the PURGE model.

PURGE4.WB2 Sheet D:		P Uptake and Removal from Grazed Ecosystems		
Plant Material on dry matter basis		Scenarios		
Method #1	Formula	1	2	3
<b>Assumptions:</b>				
Net P absorption (%)		80%	70%	60%
yearling wt (kg)		250	300	350
daily DM consumption (%)		2.50%	2.75%	3.00%
P conc. in grass (%)		0.25%	0.28%	0.30%
stocking rate (hd-mon/ha)		3	4	5
area grazed (ha)		17,668	17,668	17,668
rate of gain (kg/hd-day)		0.5	0.75	1
<b>Calculations:</b>				
carrying capacity (hd-mon)	+B10*B11	53,004	70,672	88,340
total weight gain (Mg)	+B14*B12*30/1000	795	1,590	2,650
grass consumed/hd-day (kg)	+B7*B8	6.25	8.25	10.5
P consumed/hd-day (kg)	+B16*B9	0.02	0.023	0.032
P retained/hd-day (kg)	+B17*B6	0.01	0.016	0.019
P removed with cattle (Mg)	+B18*B14*30/1000	19.88	34	50
<b>Method #2</b>				
<b>Assumptions:</b>				
forage production (kg/ha)		2,000	4,000	6,000
P conc. in grass (%)		0.25%	0.28%	0.30%
ratio of P removed/plant uptake		0.04	0.08	0.12
<b>Calculations:</b>				
P removed with cattle (kg/ha)	+B23*B24*B25	0.2	0.88	2.16
P removed from watershed (Mg)	+B11*B27/1000	3.53	16	38
<b>Method #3 (Bull 1995)</b>				
<b>Assumptions:</b>				
same total weight gain as above		fresh bone = 4.5% P		
bone growth is about 20% of the animal growth		bone P = 80% of total body P		
<b>Calculations:</b>				
weight gain as bone (Mg)	+B15*0.2	159	318	530
P in bone growth (Mg)	+B35*0.045	7	14	24
non-bone P from gain (Mg)	+B36/4	2	4	6
Total P from gain (Mg)	+B36+B37	9	18	30



hay or by grazing. If P is not supplemented, and grazing animals gain weight and are removed from the watershed, then P is exported in the animal tissue.

The amount of P exported with grazing cattle estimated by the PURGE model is shown in Table 2. Depending on the scenario and method used within the model, the amount of P exported varied from 4 to 50 Mg per 17,700 ha. An average of the moderate values (scenario 2) across the three methods results in 23 Mg P removed from 17,700 ha of pasture lands in the Cascade Watershed annually.

## DISCUSSION

### THE P CYCLE ON A GRAZED OR HAYED PASTURE

Effects of livestock grazing on nutrient loading are reported with mixed conclusions. Some report that grazing has no measurable impact on N and P pools in soils of infrequently flooded, upland grasslands. Other and sometimes nonscientific papers report that grazing increases P in streams, but these monitoring studies often have inappropriate designs for determining cause and effect. It is clear that any activity accelerating erosion will increase total P load. It isn't clear what effects grazing has on soluble P loading to streams and reservoirs.

Proper grazing management is essential to reducing nutrient loadings to streams. In Oklahoma, Olness et al. (1980) reported that total P concentrations in surface runoff from continuously grazed watersheds ranged from 1 to 1.8 ppm, and were about three times higher than those from rotation-grazed watersheds because of greater soil loss. Average annual losses in runoff from the same rotationally grazed and continuously grazed watersheds were 0.56 and 1.9 kg total P/ha, respectively (Menzel et al. 1978), over a 4-year period. In contrast, Tiedemann et al. (1989) found that differences among grazing strategies for P concentration in streamwater were not significant after the average daily streamflow was used as a covariate in a 5-year study on 13 wildland watersheds in eastern Oregon. In northern Idaho, Jawson et al. (1982) reported annual total P losses in runoff from a grazed watershed over 3 years ranged from 0.1 to 1.3 kg/ha and from 0.1 to 0.17 kg/ha for the ungrazed watershed. However, the watershed effect may be confounded in the study and comparisons are difficult because of differences in topography, vegetative cover, and intensity of precipitation.

There may be a potential for livestock grazing to increase P loading in overland flow situations because the eating and digestion of plant material reduces the particle size in the fecal material containing the undigested P. However, much of the P in the undigested plant material may be in insoluble forms.

Much of the P cycled through animals returns to the surface as dung pats but patterns of dung and urine deposition are not uniform. Such patterns may be more distinct with sheep where from 1 to 2 kg P/ha annually may be transported to ridges where sheep camp at night (Haynes & Williams 1993). Theoretically a BMP of high-intensity and short-duration grazing should provide more uniform dung distribution. However, in a Florida study, soil P redistribution was not different among short-duration, long-duration, and continuous grazing systems on Bermuda grass, but accumulated in the third of the pastures closest to shade and water, probably a result of urine and feces deposition by cattle (Mathews et al. 1993).

Livestock grazing, assuming it is performed with best management practices, in fact removes P from the ecosystem, thereby reducing the extractable soil P. This should produce a greater P sink capacity in the soil because the Fe and Al oxides would still be available to adsorb P from leached plant residue, feces, and urine or from infiltration of water into the soil.

### EXPORT OF P

Using moderate values in the PURGE simulation, the model produced an estimate of 23 Mg P removed from the basin, or 1.3 kg P/ha removed. Linqian and Tingcheng (1993) reported that native range in northeastern China dominated by *Leymunes chinenses* could have 1.5 kg P/ha exported annually as hay, which was 21% of the P balance. Wilkinson (1973) calculated that a grazing 500 kg bovine removed 3.3 kg P from the soil into the animal body, while removing 11 Mg of tall fescue hay exported 38 kg P/ha.

Lavado et al. (1996) reported lower soil extractable P in grazed pastures than in pastures excluded from grazing for 13 years on the Pampas in Argentina. Similarly, total P was 4 kg/ha larger in relict than grasslands grazed for 75 years on the Great Plains (Bauer et al. 1987). Diarra et al. (1995) reported 0.15 kg P/ha exported as animal product from the arid Sahel.

Martin and Molloy (1971) estimated the amount of organic P annually contained on a grazed pasture was 269, 6.2, 9, and 3 kg P/ha for a 7.6-cm soil depth, feces, residual herbage, and roots, respectively. They estimated inorganic P annually contained on a grazed pasture was 470, 35, 13, and 4 kg P/ha for a 7.6-cm soil depth, feces, residual herbage, and roots, respectively. The inorganic P in feces seems high in this data and could result from some soil contamination.

## RESEARCH AND MANAGEMENT IMPLICATIONS

### RECOMMENDATIONS OF BEST MANAGEMENT PRACTICES

Grass buffer strips can be effective in reducing P transport from pastures by increasing infiltration, sedimentation, and decreasing overland flow. Off-stream water development and fencing of riparian areas should reduce (1) streambank degradation, and (2) direct deposit of feces and urine in streams. Rotational grazing systems should provide for a healthier pasture.

Degraded water quality is not beneficial to recreationists, wildlife, homeowners, or agricultural producers. Everyone benefits from using BMPs and other tools—based on science rather than perceptions—to reduce P loading. Recreational and grazing activities that accelerate erosion will increase total P loadings because of P association with soil particles. We should also recognize that properly managed livestock grazing operations will export P from the basin.

### RESEARCH NEEDS

The effects of grazing need to be determined by using a design of randomized and replicated treatment areas within the same watershed, and multiple years and watersheds. Volume and nutrient concentration of overland flow and leachate should be measured on these plots as often as every other day during peak snow melt conditions, and as often as twice per week during the grazing season. Overland flow and leachate should be monitored during high, medium, and low runoff years, and total and soluble P concentration should be measured in the soil, forage, and feces in temporal and spatial scales. Cattle gains should be recorded to verify the input variables used in this model. By using a mass balance approach, accounting for most of the P cycling in the ecosystem should be possible. Radioactive isotopes also could be used to trace P cycling in extracted soil cores. Knowing the cycling times and forms should provide insight into adjusting BMPs.

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## Monitoring runoff from cattle-grazed pastures for a phosphorus loss quantification tool

Peter A. Vadas

USDA-ARS, U.S. Dairy Forage Research Center, [peter.vadas@ars.usda.gov](mailto:peter.vadas@ars.usda.gov)

Dennis L. Busch

University of Wisconsin-Platteville

J. Mark Powell

USDA-ARS, [mark.powell@wisc.edu](mailto:mark.powell@wisc.edu)

Geoff E. Brink

USDA-ARS, U.S. Dairy Forage Research Center, [Geoffrey.Brink@ars.usda.gov](mailto:Geoffrey.Brink@ars.usda.gov)

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# Monitoring runoff from cattle-grazed pastures for a phosphorus loss quantification tool

Peter A. Vadas<sup>a,\*</sup>, Dennis L. Busch<sup>b</sup>, J. Mark Powell<sup>a</sup>, Geoff E. Brink<sup>a</sup>

<sup>a</sup> USDA-ARS, U.S. Dairy Forage Research Center, 1925 Linden Drive West, Madison, WI 53706, United States

<sup>b</sup> University of WI-Platteville School of Agriculture, United States

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## ABSTRACT

Nitrogen (N) and phosphorus (P) loss from agriculture persists as a water quality impairment issue. For dairy farms, nutrients can be lost from cropland, pastures, barnyards, and outdoor cattle lots. We monitored N and P loss in runoff from dairy and beef grazed pastures for two years in southwest Wisconsin, USA and tested the accuracy of the Annual P Loss Estimator (APLE) model to predict runoff P from pastures using study and literature data. About 3–10% of annual precipitation became runoff from the pastures, and sediment loss was very low due to well-established vegetation. Measured annual nutrient loss in runoff was also low, averaging  $1.0 \text{ kg ha}^{-1}$  for total P and  $2.9 \text{ kg ha}^{-1}$  for total N. Runoff sediment and particulate N and P concentrations were well related to each other and tended to be greater in rainfall-induced runoff than snowmelt runoff. Conversely, dissolved N and P runoff concentrations were greater in snowmelt runoff. APLE was able to reliably predict annual P loss in runoff, estimating that the average relative contribution to total pasture P loss was about 10% from fertilizer, 15% from soil dissolved P, 30% from dung, and 45% from soil erosion. Our study has increased the ability to develop reliable models for estimating the impact of cattle grazing pastures on nutrient runoff, which will be valuable in estimating whole-farm P loss from dairy production systems and identifying areas on dairy farms where P loss remediation should be targeted.

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## 1. Introduction

Non-point source pollution of surface waters by nitrogen (N) and phosphorus (P) can accelerate eutrophication and limit water use for drinking, recreation, and industry (Parris, 2011). Because N and P loss from agricultural systems via surface runoff has consistently been identified as a non-point pollution source (Bennett et al., 2001), there is a need to quickly and accurately quantify runoff nutrient loss from farms, identify the major sources of farm loss, and develop management practices to reduce that loss. For cattle farms, possible sources of runoff N and P loss include cropland, grazed pastures, and outside cattle holding areas, such as feedlots, barnyards, exercise lots, or over-wintering lots. On such farms, it is necessary to estimate nutrient loss in runoff from all of these sources to effectively target remediation practices (McDowell and Nash, 2012).

There has been significant research conducted to monitor N and P loss in runoff from grazed pastures (Edwards et al., 2000; Halliwell et al., 2000; Nash et al., 2000; O'reagain et al., 2005; Haan et al., 2006;

Owens and Shipitalo, 2006; Capece et al., 2007; McDowell et al., 2007; Dougherty et al., 2008). However, considerably less pasture runoff research has been conducted compared to nutrient loss from cultivated cropland, and most of it has been conducted in Australia, New Zealand, and the United Kingdom. In the U.S., only limited field-scale, natural precipitation, pasture runoff research have been conducted where the major source of nutrient addition is through grazing animals (Olness et al., 1975; Menzel et al., 1978; Chichester et al., 1979; Schepers and Francis, 1982; Owens and Shipitalo, 2006; Capece et al., 2007). The reason for this is unclear. It may be that relative to row crops, pastures constitute much fewer acres on cattle farms in areas where water quality impairment is a problem and are not seen as a major contributor to waterbody eutrophication, especially since pastures typically have less nutrient inputs and soil erosion than row crops. However, as the demand for improved water quality increases, the use of pastures and the associated decrease in nutrient loss through soil erosion may become a more attractive land use on cattle farms (Rotz et al., 2009). There is thus a need to document the potential water quality impact of cattle pastures and have tools to estimate this impact relative to other land uses on cattle farms.

As quantifying runoff nutrient loss from all sources on a cattle farm through physical monitoring is expensive and lengthy,

\* Corresponding author. Tel.: +1 608 890 0069; fax: +1 608 890 0076.  
E-mail address: [peter.vadas@ars.usda.gov](mailto:peter.vadas@ars.usda.gov) (P.A. Vadas).

simulation models can be a more rapid, cost effective ways to estimate N and P loss (Radcliffe et al., 2009). For P, quantitative agricultural loss models can generally be grouped into two categories. The first group is highly parameterized, daily time-step, process-based models like the farm-scale Integrated Farm Systems Model (IFSM) (Sedorovich et al., 2007), or field to watershed-scale models like the Soil and Water Assessment Tool (SWAT) (Arnold et al., 1998) or the Agricultural Policy/Environmental eXtender (APEX) (Gassman et al., 2010). The second group is more user-friendly, seasonal to annual time-step models, such as the Annual P Loss Estimator (APLE) (Vadas et al., 2009, 2012) and the Wisconsin P Index (WI PI) (Good et al., 2012), that are a combination of process-based and empirical P loss equations. However, all of these tools have shortcomings when simulating P loss via surface runoff from cattle-grazed pastures. The WI PI and APLE have been developed to estimate P loss from agricultural cropland, but have not been tested for grazed pastures; IFSM apparently does not simulate P loss from dung deposited during grazing; and currently available versions of SWAT and APEX do not simulate manure or dung on the soil surface, which precludes adequate simulation of P loss from dung in pastures. Therefore, these tools should be updated to better simulate P loss from dairy farms in general and cattle-grazed pastures in particular. Vadas et al. (2011) recently developed a daily time step model for P loss from grazing cattle pastures that could be integrated into models like IFSM, SWAT, and APEX. Similar updates are needed for annual models like APLE and the WI PI.

The objectives of our project were to: (i) monitor N and P loss in runoff from beef and dairy-grazed pastures in southwest Wisconsin, USA, and (ii) use the runoff data, as well as data from published scientific literature, to test the ability of APLE to predict P loss in runoff from cattle-grazed pastures. The long-term goal of this research is to develop modeling tools that can estimate whole-farm P loss from dairy farms and appropriately target farm areas for P loss remediation. Assessing the pasture component of dairy farms is one step in that process.

## 2. Methods and materials

### 2.1. Pasture runoff monitoring

We established eight, hydrologically isolated basins ranging in size from 0.3 to 0.4 ha in an existing cattle pasture at the University of Wisconsin-Platteville Pioneer Farm (42.71°N, 90.39°W) (Fig. 1). The Pioneer Farm is a 174 ha production



Fig. 1. Aerial view of the field showing the location of the eight runoff basins within an existing cattle pasture.

farm located in the unglaciated area of southwest Wisconsin in the Northern Mississippi Valley Loess Hills. The dominant soil is a moderately eroded Tama soil series (fine-silty, mixed, super-active, mesic Typic Argiudoll), with B and C slope classes. The runoff basins were oriented so that four were on a south-facing slope (5–8%) and four were on a north-facing slope (5–8%), with a ridge separating the two groups. The eight basins were within existing pastures grazed by beef and non-lactating dairy cattle, and were separated from each other either by the ridge at the upslope edge or by earthen berms. The southern four basins were within a 7.3 ha pasture grazed by beef cattle, and the northern four basins were within a 6.1 ha pasture grazed by non-lactating dairy cattle. Thus, the eight basins all received generally the same management. Cattle were given free access to the pastures starting in mid-May until mid-November, with daily numbers of dairy cattle ranging from 14 to 34 and beef cattle from 18 to 28. Annual stocking rates were approximately 2.7 animal units ha<sup>-1</sup>, with one animal unit defined as a mature cow at about 450 kg. Excess pasture growth was cut for hay and baled, typically in mid-July. This management for non-lactating cattle is typical for this region, with cattle generally given access to pastures for grazing from early to mid spring until late fall, with supplemental feeding as needed. Outside of this period, cattle are housed off of pastures, typically in small, dedicated lots known as over-wintering areas.

We installed runoff collection systems at the outlet of each basin. Each system consisted of wooden wing walls that channeled surface runoff into an H-flume. Ultrasonic sensors (Automated Products Group IRU-5000) measured and logged (Campbell Scientific CR206) water stage in the flumes in one-minute intervals to estimate runoff volumes. Flow-paced composite runoff samples were collected from flumes using an automated sampler (ISCO 3700), with sampling frequency adjusted remotely for each event to ensure collection of representative samples for an entire event, such that samples were collected more frequently as flow increased. Samples were pumped into 1-L containers and collected within 24 h of the end of the runoff event. A discharge-weighted sample was then produced for each runoff event by calculating the percentage of the total runoff-event volume that each discrete sample represented, collecting appropriate aliquots from each discrete sample by using a churn splitter, and combining aliquots into one composite sample. Flow-compositing monitoring is a common procedure that reliably estimates pollutant loads for runoff events (Harmel and King, 2005).

The sampling system was inside a covered shelter and was equipped with radiant heaters to allow runoff collection year round. We measured daily rainfall with existing equipment at the Pioneer Farm, and obtained snowfall data from a weather station located ~35 km to the southwest of the field site. In this region, there is predominately frozen precipitation from December through March. Runoff from snowmelt and rain-on-snow events is typical throughout February and March and can account for a majority of total annual runoff. Outside of this snowmelt period, runoff does occur, but is typically less and occurs inconsistently, often as a result of large storms.

The runoff sampling protocol described above generated a single, composite runoff sample for each event for each runoff basin. We analyzed all composite runoff samples for sediment, N, and P at the USDA-ARS Dairy Forage Research Center in Madison, WI. We measured total sediment gravimetrically by drying a known quantity (~50 mL) of a well-shaken runoff sample at 60 °C until all water had evaporated. We then determined the weight of the remaining sediment and determined sediment content (g L<sup>-1</sup>) as the mass of that sediment in the original volume of sample. We filtered runoff samples through 0.45 µm filters, and analyzed filtered samples for dissolved P (Murphy and Riley, 1962), and



$\text{NH}_4\text{-N}$  and  $\text{NO}_3\text{-N}$  using QuickChem methods 12-107-06-2-A (ammonium) and 12-107-04-1-B (nitrate) on a Lachat automated N analyzer (Lachat, 1996). To measure total N and P, we digested unfiltered samples in an autoclave with potassium persulfate, with digested samples analyzed for N and P by the same methods as the filtered samples (Langner and Hendrix, 1982). We refer to the difference between total and dissolved nutrient forms as particulate N or P.

We collected soil samples from each pasture basin from 0–2.5 and 0–15.0 cm to assess the historical P accumulation in soils and the degree of P stratification (i.e., greater P in the 0–2.5 cm layer than the 0–15.0 cm layer due to historical surface manure applications and minimal soil mixing due to lack of tillage). Soil samples were analyzed at the University of Wisconsin Soil and Plant Analysis Lab for Bray-1 P extractable soil P (Bray and Kurtz, 1945) and organic matter (OM) by loss-on-ignition. These data were used as inputs for the APLE model as described below.

## 2.2. Determination of event and annual N and P loads

To determine event sediment, N, and P loads from each pasture basin, we multiplied the concentration of sediment and measured N and P forms ( $\text{mg L}^{-1}$ ) in runoff samples by the runoff amount from each basin ( $\text{L ha}^{-1}$ ) to determine a load ( $\text{kg ha}^{-1}$ ). Analysis of runoff and nutrient loss data did not reveal any consistent trends in differences between the eight basins. Given this and that all pasture basins had similar management, we treated the basins as replicates and averaged loads across all eight for a single load per event. For annual sediment or nutrient loads, we summed all event loads for two 365-d periods, which were from August 1 to July 31 for both 2010–2011 and 2011–2012.

## 2.3. Testing APLE for runoff P loss from pastures

### 2.3.1. APLE description

APLE is a fairly simple, user-friendly, Microsoft Excel spreadsheet model that runs on an annual time-step and estimates field-scale, sediment bound and dissolved P loss ( $\text{kg ha}^{-1}$ ) in surface runoff for agricultural field. APLE is intended to have the simplicity of P-indexes, but to quantify P loss through more process-based equations rather than estimate a risk of P loss. It has been tested for its ability to reliably predict P loss in runoff for systems with machine-applied manure and for soil P cycling using data from a wide variety of agricultural fields and regions (Vadas et al., 2007, 2012). APLE is available to download at (<http://ars.usda.gov/Services/docs.htm?docid=21763>), along with theoretical documentation and a user's manual that describe the model in detail. Here, we present a summary of APLE and how we adapted and tested it for P loss in runoff from grazed pastures.

Pertinent APLE user-input data for this project include topsoil properties (Mehlich-3 soil test P, clay, organic matter); surface area of the field; annual precipitation, runoff, and erosion; annual crop P export; number of annual cattle days in the field; and information for manure and fertilizer P application. APLE operates on an annual time-step, and therefore does not consider variations in climate, hydrology, or other variables that occur throughout a year. It also does not consider landscape or management impacts on runoff and erosion, but instead allows user-input precipitation, runoff, and erosion to account for these variations. Thus, APLE does not predict annual runoff or erosion, but instead estimates P loss and soil P cycling for a given set of runoff, erosion, and P application (fertilizer, manure, grazing) conditions. Annual erosion and runoff can be estimated with models such as RUSLE2 ([http://fargo.nserl.purdue.edu/rusle2\\_dataweb/RUSLE2\\_Index.htm](http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm)).

APLE estimates annual sediment P loss ( $\text{kg ha}^{-1}$ ) in runoff as:

$$\text{Sediment P loss} = (\text{eroded sediment})(\text{soil total P})(\text{P enrichment ratio})(10^{-6}) \quad (1)$$

where eroded sediment ( $\text{kg ha}^{-1}$ ) is annual soil erosion; soil total P ( $\text{mg kg}^{-1}$ ) is estimated using soil Mehlich-3 P, clay, and OM; and P enrichment ratio is a unitless ratio of total P in eroded sediment to that in the source soil, and is estimated from annual soil erosion. In this study, we used measured soil Bray-1 P and OM data and assumed that Mehlich-3 was equivalent to Bray-1 (Vadas et al., 2012). APLE estimates dissolved inorganic P loss in runoff ( $\text{kg ha}^{-1}$ ) from soil as:

$$\text{Dissolved soil runoff P} = (\text{soil labile P})(0.005)(\text{annual runoff})(10^{-6}) \quad (2)$$

where soil labile P ( $\text{mg kg}^{-1}$ ) is estimated as one half of soil Mehlich-3 P and annual runoff is in cm.

In APLE, manure is applied in either a solid or liquid form, and fertilizer in a solid form. If tillage occurs, APLE incorporates any applied manure or fertilizer according to user-specified depths of incorporation and percentages of P applied that are incorporated. APLE estimates annual dissolved P loss directly from any manure or fertilizer remaining on the soil surface. For applied manure, APLE assumes a portion of the manure total P is in a water-extractable P (WEP) form. APLE estimates dissolved manure P loss in runoff from this manure WEP on the soil surface. The portion of manure P that is not in a WEP form (non-WEP) at application can mineralize during the year and add to manure WEP on the soil surface. APLE estimates annual manure or fertilizer dissolved P loss in runoff ( $\text{kg ha}^{-1}$ ) as:

$$\text{Manure runoff P} = (\text{manure WEP})(\text{annual runoff/precipitation})(\text{P distr. factor}) \quad (3)$$

$$\text{Fertilizer runoff P} = (\text{fertilizer P})(\text{annual runoff/precipitation})(\text{P distr. factor}) \quad (4)$$

where manure WEP and fertilizer P are in  $\text{kg ha}^{-1}$  and precipitation and runoff are in cm. The P distribution factor is an empirical factor between 0.0 and 1.0 that distributes released P between runoff and infiltration, and is calculated as:

$$\text{Manure: P distribution factor} = (\text{annual runoff/precipitation})^{0.225} \quad (5)$$

$$\text{Fertilizer: P distribution factor} = 0.034 \exp((3.4)(\text{annual runoff/precipitation})) \quad (6)$$

The precipitation (cm) represents total rain, snow, and irrigation for an entire 12-month period.

### 2.3.2. APLE testing for pastures

The processes described above for P loss in runoff from soil, manure, and fertilizer have been well tested (Vadas et al., 2009; Good et al., 2012). For this project, we adapted and tested APLE so it would simulate P loss in runoff from dung applied by grazing cattle. In APLE, a user specifies how many dairy or beef cattle graze the field during the year. This adds dung and P to the field and increases the amount of dissolved P loss in runoff. APLE assumes daily dung production and dung total P content for dairy and beef cattle as listed in Table 1 (Nennich et al., 2005). Dung WEP at deposition is set at 55% of total P, and 75% of dung WEP is available the same year for P loss in runoff and 25% is available the following year. APLE also assumes that 20% of dung non-WEP on the soil surface mineralizes into WEP the same year.

Table 1

Assumptions used in the APLE model for daily dry mass dung production and dung total P content for grazing dairy and beef cattle.

Animal type	Daily dung production kg	Dung total P content kg kg <sup>-1</sup>
Lactating dairy cow	8.9	0.0088
Dairy heifer	3.7	0.0054
Dairy dry cow	4.9	0.0061
Dairy calf	1.4	0.0054
Beef cow	6.6	0.0067
Beef calf	2.7	0.0092

APLE uses Eqs. (3) and (5) to calculate annual dissolved P loss in runoff from grazing dung. In addition, APLE also reduces the amount of dung dissolved P loss in runoff by a factor that accounts for the fact that dung does not evenly cover the entire soil surface, as would be the case for machine applied manure, and not all of the annual precipitation interacts with it to contribute to runoff P. In calculating the annual reduction factor for grazing dung, APLE first assumes that each 250 g of dung (dry weight) covers an area of 659 cm<sup>2</sup> (James et al., 2007) and calculates what percentage of the field area is covered by the annual mass of dung deposited. APLE then calculates the dung reduction factor as:

$$\text{Reduction factor} = 1.2 \times (250 \times \% \text{ annual cover}) / ((250 \times \% \text{ annual cover}) + 73.1) \quad (7)$$

where % annual cover is expressed as a decimal. Eq. (7) is a non-linear equation that returns a reduction factor greater than the portion of the pasture area covered by dung. We found that during APLE adaptation for pasture P runoff, a non-linear equation gave better predictions of dissolved P loss in runoff than a linear equation that reduced runoff P in direct proportion to the pasture area covered by dung. Eq. (7) is taken from the daily time-step, manure P runoff model of Vadas et al. (2007), where it is used to determine what portion of manure WEP is leached by rain from manure on the soil surface during a storm. Thus, the important new parts of APLE to test were the assumptions for cattle dung production rate and P content (Table 1) and Eq. (7) to reduce dung P loss in runoff according to the amount of pasture area covered.

To test APLE for grazing cattle, we used data from 20 published studies in the literature that monitored field-scale P loss in runoff from grazed pastures (Table 2), as well as data from our pasture runoff monitoring. All literature studies were conducted for at least

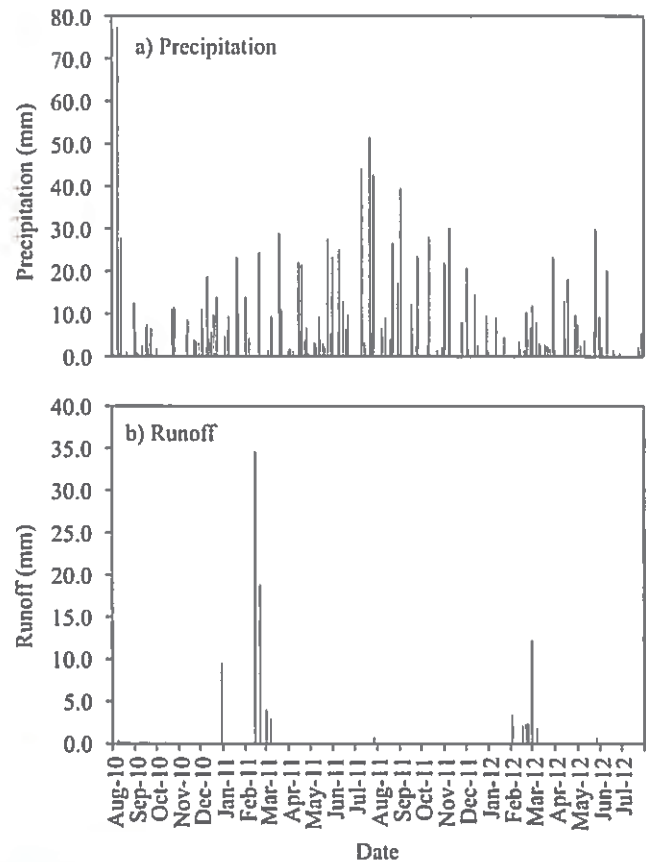


Fig. 2. Precipitation and runoff depths from the eight pasture basins from August 2010 to July 2012.

6 months, and most for multiple years. The studies all reported the input information needed for APLE, including size of field; annual stocking rate; soil P concentration; fertilizer applications; soil OM and clay content; and annual rain, runoff, and sediment loss. We entered all required input information into APLE, predicted annual P loss in runoff, and then compared measured and predicted P loss (both total P and dissolved P) by linear regression to assess how reliably APLE simulated annual P loss from grazed pastures.

Table 2

Details of 20 studies used to validate APLE for P loss in runoff from cattle-grazed pastures.

Reference	Location	Duration months	Field area ha	Cattle type	P forms measured
(Capece et al., 2007)	Florida, USA	72	20.2–32.4	Beef	DRP
(Cournane et al., 2011)	New Zealand	25	1.3	Beef	TP, DRP
(Edwards et al., 1996)	Arkansas, USA	24	1.2	Beef	DRP
(Fleming and Cox, 1998)	Australia	12	2.4	Dairy	DRP
(Harmel et al., 2009)	Texas, USA	84	1.2	Beef	TP, DRP
(Holz, 2010)	Tasmania	36	12.1	Dairy	TP, DRP
(Kurz et al., 2006)	Ireland	16	0.5–1.5	Beef	DRP
(Lambert et al., 1985)	New Zealand	36	0.1–1.5	Sheep	TP
(Mapfumo et al., 2002)	Canada	36	2.2	Beef	DRP
(McDowell et al., 2003)	New Zealand	6	3.0	Dairy	TP, DRP
(Melland et al., 2008)	Australia	30	0.5	Sheep	TP
(Menzel et al., 1978)	Oklahoma, USA	120	11.0	Beef	TP, DRP
(Olness et al., 1975)	Oklahoma, USA	12	9.6–11.0	Beef	TP, DRP
(O'Reagain et al., 2005)	Australia	12	1.0	Beef	TP
(Owens and Shipitalo, 2006)	Ohio, USA	120	17.2	Beef	DRP
(Owens et al., 1983a)	Ohio, USA	72	28.2	Beef	TP
(Schepers and Francis, 1982)	Nebraska, USA	36	32.5	Beef	TP, DRP
(Smith, 1987)	New Zealand	20	16	Sheep	TP, DRP
(Smith and Monaghan, 2003)	New Zealand	36	0.09	Beef, dairy	DRP
(Vankeuren et al., 1979)	Ohio, USA	24	17.2	Beef	TP

### 3. Results and discussion

#### 3.1. Runoff monitoring at Pioneer Farm

Fig. 2 shows precipitation and runoff depths for our pasture-monitoring period between August 2010 and July 2012. There were 16 runoff events during this period that generated 102 runoff samples (Table 3), meaning that not all eight basins had runoff for all events. Only five events and 30 samples were caused by rain outside of winter periods (December 1–March 31), with all other events and samples due to snowmelt or rain-on-snow. Although runoff is clearly weather dependent, these data suggest that most runoff from pastures in Wisconsin on similar soil types may occur in winter and early spring from snowmelt, with less runoff from rain outside of this period.

Tables 3 and 4 show results for sediment and nutrient loss in runoff for the grazed pastures. In the 102 runoff samples, sediment concentrations were consistently very low, averaging only  $0.20 \text{ g L}^{-1}$ , with a maximum of only  $1.3 \text{ g L}^{-1}$ . Sediment runoff concentrations did not vary appreciably through time. However, average sediment runoff concentrations were greater during the non-winter period than the winter period, showing that rainfall-induced runoff was more erosive than snowmelt runoff. Overall though, data clearly show that well-established pasture vegetation can effectively eliminate soil erosion (Owens et al., 1983b; Butler et al., 2006; Bartley et al., 2010).

Runoff dissolved  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$  concentrations were generally low throughout the study and did not vary substantially through time (Tables 3 and 4). Particulate runoff N concentrations (total N less  $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$ ) were fairly well, non-linearly related to runoff sediment concentrations (particulate  $\text{N} = 1.03 \times \ln \text{ runoff sediment} - 1.85$ ;  $r^2 = 0.46$ ). Runoff particulate

P concentrations were similarly related to runoff sediment (particulate  $\text{P} = 0.24 \times \ln \text{ runoff sediment} - 0.69$ ;  $r^2 = 0.43$ ). Strong relationships between sediment loss and particulate nutrient loss are common (Vadas et al., 2004; Kleinman et al., 2011). Generally, runoff P concentrations did not vary drastically through time. About 80% of runoff samples had dissolved P between 0.5 and  $2.5 \text{ mg L}^{-1}$ , and total P between 1.0 and  $3.0 \text{ mg L}^{-1}$ . Dissolved P averaged 80% of total P in the winter-period, snowmelt samples and 60% in the non-winter, rain-runoff samples. The magnitude of these P concentrations is consistent with runoff observations from the similar study of Owens and Shipitalo (2006), where well established pastures were grazed by beef cattle over several years under similar climate conditions in Ohio, USA.

The chemical forms of runoff nutrient concentrations did vary as a function of season. Average particulate N and P concentrations were greater during the non-winter period ( $3.83$  vs  $3.25 \text{ mg L}^{-1}$  for N, and  $0.63$  vs  $0.43 \text{ mg L}^{-1}$  for P), which follows the runoff sediment data. These results were statistically significant ( $p = 0.05$ ) for P, but not for N. Conversely, dissolved N and P concentrations were both significantly ( $p = 0.05$ ) greater during the winter period. This is despite the relatively long time between fresh dung deposition during grazing and winter runoff events, which is somewhat contrary to research that shows nutrient concentrations in runoff are often greatest shortly after grazing events (Dougherty et al., 2008). Greater winter dissolved nutrient concentrations, especially for P, may have been caused by freezing of vegetation and associated greater release of nutrients upon thawing, which may not occur for dung (Miller et al., 1994; Bechmann et al., 2005). Overall, the increase in particulate concentrations during non-winter periods was less than the increase in dissolved concentrations during the winter period, so that overall total nutrient runoff concentrations were greater

Table 3

Date, runoff depths, and flow-weighted sediment and nutrient concentrations in runoff for the 16 individual runoff events monitored from August 2010 to July 2012. Data for a given event are averages of the eight cattle pasture basins.

Date	Runoff	Sediment	Dissolved P	Total P	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	Total N
	cm	$\text{mg L}^{-1}$					
8/8/10	0.04	108.81	0.51	0.84	0.54	0.40	4.37
8/9/10	0.03	225.77	0.71	1.26	0.59	0.61	4.82
8/13/10	0.04	156.35	1.02	1.53	0.80	0.39	4.88
12/30/10	0.96	74.65	1.46	1.60	0.75	0.73	2.93
2/14/11	3.47	80.38	1.99	2.27	5.07	0.75	9.10
2/20/11	1.88	69.68	1.26	1.48	2.47	0.72	5.33
3/1/11	0.41	123.92	1.62	2.14	3.11	0.83	3.76
3/7/11	0.30	295.42	3.25	4.09	3.05	1.81	9.19
7/27/11	0.07	567.66	1.33	2.26	0.33	1.31	5.58
2/2/12	0.34	167.35	2.11	2.82	1.97	1.09	6.14
2/17/12	0.21	72.53	1.81	2.17	1.37	0.47	4.19
2/21/12	0.23	112.23	1.74	2.13	1.68	0.82	5.11
2/24/12	0.23	377.48	1.71	2.24	1.44	0.81	6.60
2/29/12	1.22	239.57	1.26	1.74	1.24	0.40	5.29
3/7/12	0.18	269.18	2.38	2.94	1.26	0.78	6.25
5/26/12	0.07	388.07	2.55	3.50	3.48	0.80	12.03

Table 4

Summary statistics for runoff depths, and flow-weighted sediment and nutrient concentrations in runoff for the eight cattle pasture basins and 16 runoff events monitored from August 2010 to July 2012. Data are across all samples for all events.

Statistic	Sediment $\text{mg L}^{-1}$	Dissolved P	Total P	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$	Total N
Average	200.1	1.5	2.0	1.8	0.8	5.9
Maximum	1331.8	4.3	5.2	12.3	4.4	21.0
Minimum	13.3	0.1	0.5	0.1	0.0	2.4
Std. dev.	206.3	0.8	0.9	2.0	0.5	3.2
Winter average	152.7	1.7	2.2	2.3	0.8	6.1
Non-winter average	279.9	1.0	1.5	0.7	0.7	5.2



Table 5

Measured 12-month period precipitation, runoff, and sediment and P loss in runoff from cattle pastures from August 2010 to July 2012.

Time period	Precipitation cm	Runoff cm	Sediment kg ha <sup>-1</sup>	Dissolved P kg ha <sup>-1</sup>	Total P kg ha <sup>-1</sup>
2010–2011	86.0	6.7	66.6	1.2	1.4
2011–2012	58.3	2.0	62.6	0.4	0.6

during the winter period. These results were statistically significant ( $p=0.05$ ) for P, but not for N.

We compiled measured runoff volume and sediment and P concentration data from all events to calculate annual runoff, erosion, and P loss from the cattle pastures (Table 5). Both annual precipitation and runoff were greater in the 2010–2011 period than the 2011–2012 period. Average annual precipitation for this location (1971–2001) is 91.7 cm. Thus for years with about average precipitation (2010–2011), about 5–10% of annual precipitation may be expected to become runoff from similar grazed cattle pastures. In years with less than average precipitation (2011–2012), less than 5% of precipitation may become runoff. These results are consistent with data from Owens and Shipitalo (2006) where average annual runoff from grazed pastures ranged from about 2 to 13% of average annual precipitation. Such information is useful for models like APLE that require annual precipitation and runoff as input. Model users will readily know typical annual precipitation, and annual runoff can be estimated as a percentage of that precipitation for a given soil type and land use. Thus, a model user could be confident in assuming annual runoff from similar pastures may be 5–10% of annual precipitation.

Annual erosion from the pastures was very low, at less than 70 kg ha<sup>-1</sup>, and annual nutrient loss was only 1.5–4.3 kg total N ha<sup>-1</sup> P and 0.6–1.6 kg total P ha<sup>-1</sup>. These P results are consistent with data in the literature on the magnitude of P loss from grazed pastures. For example, of the 20 pasture runoff studies in Table 2, about 85% of the site years had less than 2.0 kg ha<sup>-1</sup> of annual total P loss and less than 1.5 kg ha<sup>-1</sup> of dissolved P loss. Based on our cattle stocking rates, and assuming that cattle excrete 0.23 kg N day<sup>-1</sup> and 0.04 kg P day<sup>-1</sup> on a dry weight basis (Nennich et al., 2005), annual nutrient application rates to pastures were about 225 kg N ha<sup>-1</sup> and 39 kg P ha<sup>-1</sup>. Thus the rate of nutrient loss in runoff per unit of applied nutrient was about 1.3% for N and 2.5% for P. In general, these results show that annual runoff, erosion, and nutrient loss from similar cattle-grazed pastures in Wisconsin are likely low relative to other agricultural land uses (Beaulac and Reckhow, 1982), and may not pose as much of a risk to local water quality. However, management practices that increase runoff, erosion, and nutrient loss, such as significantly greater cattle stocking rates and related erosion, or excessive fertilization, could increase the risk of negative environmental impact. As demonstrated below, the APLE model could be easily used to quantify how much more P would be lost due to greater erosion, stocking rate, or fertilization.

### 3.2. Testing of APLE for P loss from cattle pastures

To assess APLE for grazing cattle, we used data from 20 published studies in the literature that monitored annual P loss in runoff from grazed pastures (Table 2). The data represented a variety of stock types, field areas, and locations and associated climate. This variety provided a robust test to see if APLE could reliably estimate annual P loss in runoff from pastures. Since we used measured runoff and erosion as model inputs, this assessment assessed the ability of APLE to reliably estimate the impact of P sources (i.e., soil P and dung P) on P loss given a set of transport (i.e., runoff and erosion) conditions.

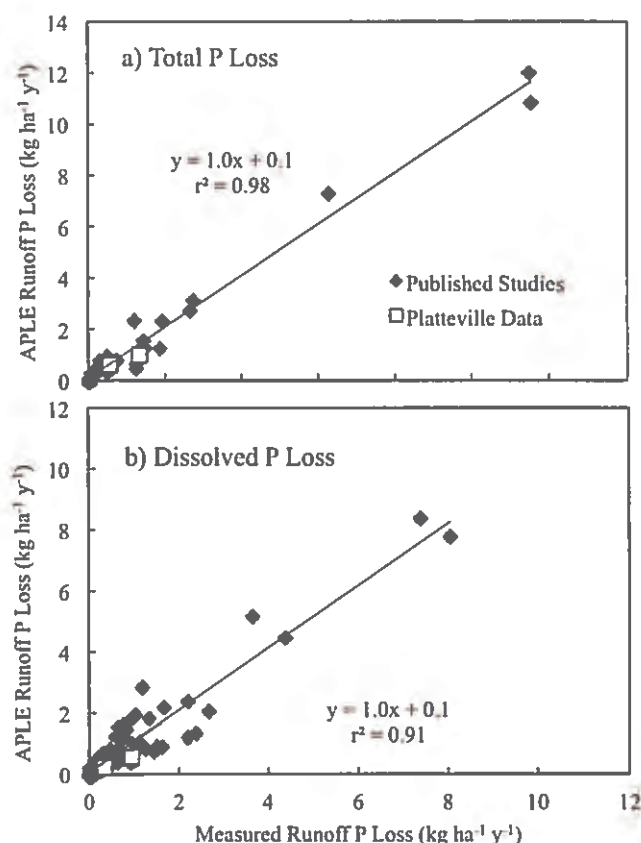


Fig. 3. Measured and APLE-simulated runoff P loss from cattle-grazed pastures. Data are from 19 published studies and from monitoring at the UW Platteville Pioneer Farm, for (a) total P in loss ( $n=33$ ) and (b) dissolved P loss ( $n=82$ ).

Fig. 3 shows the relationship between measured and predicted, annual total and dissolved P loss in runoff from cattle pastures. Results show APLE was able to reliably estimate annual P loss in runoff. The slope and intercept of both regression lines relating measured and predicted values were not significantly ( $p < 0.05$ ) different from one or zero, respectively. The model predicted the measured total P data with an efficiency of 0.98 and the dissolved P data with an efficiency of 0.89 (Nash and Sutcliffe, 1970). Nash–Sutcliffe efficiencies can range from  $-\infty$  to 1. An efficiency of 1 corresponds to a perfect match of modeled and observed data. An efficiency of zero indicates that model predictions are as accurate as the mean of observed data, and efficiency less than zero occurs when the observed mean is a better predictor than the model.

The important new parts of APLE to validate for pasture P runoff were the assumptions for dung production and P content (Table 1) and Eq. (7) to reduce dung P loss in runoff according to the amount of field area covered by dung. Runoff P prediction results in Fig. 3 suggest that these two parts of the model provided reliable estimates of pasture P runoff. In fact, without the dung area reduction factor (Eq. (7)), which would ultimately treat grazing dung the same as machine-applied manure, P loss predictions were about 50% greater than measured data. This demonstrates the importance of simulating dung deposited during grazing differently from machine-applied manure.

We also conducted a model sensitivity analysis to determine how much assumptions about dung and P production as well as dung cover influence model predictions compared to runoff volume, which is the model transport variable for manure P loss. To do this, we determined how much both increasing and

Table 6

Results of the APLE model sensitivity analysis. Data show the impact of increasing and decreasing the value of each model variable by 10% or 20% on the model prediction for annual dissolved P loss in runoff from cattle dung.

Model variable	% Change in predicted dissolved P loss in runoff from dung per change in model variable			
	+10%	–10%	+20%	–20%
Runoff	12.4	–12.1	25.0	–23.9
Dung total P excreted	10.0	–10.0	20.0	–20.0
Dung WEP content	6.0	–6.0	12.0	–12.0
Dung cover	6.0	–6.5	11.7	–13.6
Dung reduction factor	10.0	–10.0	20.0	–20.0

decreasing each variable by 10% and 20% changed model predictions for manure P loss in runoff. Specific model variables changed were runoff amount, the amount of dung total P excreted by grazing cattle, the WEP content of the grazing dung, the amount of area covered by the dung, and the reduction factor in Eq. (7). Sensitivity results are shown in Table 6. The model was most sensitive to changes in annual runoff, showing this transport factor significantly influences model prediction of dung P loss. The model was linearly sensitive to assumptions for dung total P excretion and the dung P loss reduction factor, so that each unit change in input had the same unit change in output. These changes were also nearly as much as changes for runoff volume, showing that the new assumptions developed in this project for dung P excretion and dung reduction factor are important model parameters. Model predictions were least sensitive to changes in dung WEP content and dung area covered, with the influence of these parameters about half of the influence of the previous parameters.

One benefit of the APLE model is that it gives information on the relative contribution of different sources to total P loss in runoff from pastures, including fertilizer, dung, soil, and eroded sediment. The relative importance of each source will of course depend on pasture management. For example, for the studies in Table 2 that monitored total P loss in runoff, APLE estimated that P loss from applied fertilizer ranged from 0 to 37% of total P loss, with ranges for dung from 3 to 67%, soil from 3 to 56%, and eroded sediment from 13 to 89%. However, on average for the same studies, the relative contribution to total P loss was about 10% from fertilizer, 15% from soil dissolved P, 30% from dung, and 45% from soil erosion. In New Zealand, McDowell et al. (2007) used data from a series of controlled experiments and empirical equations to make similar estimates of annual P loss from grazed pastures. They found that of the estimated P losses, fertilizer comprised 12–13%, soil P (combination of dissolved and eroded P) comprised 29–45%, dung P losses comprised 28–38%, and P from pasture-plants was 15–21%. These New Zealand P source divisions for fertilizer, soil, and dung agree well with estimates from our pasture P runoff research, except that APLE does not consider loss from pasture plants. Such P loss source data are a potentially powerful benefit of APLE and similar models for considering how to better manage P loss. Since P loss sources can vary considerably from site to site, these models become invaluable tools for site-specific P management, especially because it is infeasible to rely on physical monitoring of all sites of interest.

#### 4. Conclusions

Our project monitored sediment and nutrient loss in runoff from dairy and beef grazed pastures for typical Wisconsin conditions. Results over two annual monitoring periods show that pasture sediment and nutrient loss were generally low, likely having less negative impact on local water quality than other agricultural land uses. We used these data along with data from 20 studies in the literature, to update the APLE model to estimate annual P loss in runoff from grazed pastures. Our results demonstrate that APLE is able to reliably estimate P loss from

beef and dairy grazed pastures given reliable estimates of annual runoff and erosion. Models like APLE can be used to rapidly and cost-effectively identify which sources (i.e., dung, soil dissolved P, or particulate P) dominate P loss, making them valuable tools for site-specific P loss assessments and mitigation strategies. APLE will also play a critical role in our future research to simulate whole-farm P loss on dairy farms and identify which land uses represent the greatest risk for P loss and help target remediation.

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Review

# Livestock Manure and the Impacts on Soil Health: A Review

Natasha Rayne <sup>1,\*</sup> and Lawrence Aula <sup>2</sup><sup>1</sup> Department of Plant and Earth Science, University of Wisconsin–River Falls, River Falls, WI 54022, USA<sup>2</sup> Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, OK 74074, USA; aula@ostateemail.okstate.edu

\* Correspondence: natasha.rayne@uwrf.edu

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**Abstract:** Soil health is the capacity of the soil to provide an environment for optimum growth and development of plants, while also ensuring the health of animals and humans. Animal manure has been used for centuries as a source of nutrients in agriculture. However, many other soil properties that contribute to soil health are affected when manure is applied. Bulk density, aggregate stability, infiltration, water holding capacity, soil fertility, and biological properties are impacted to various degrees with manure application. The goal of this paper was to compile the research findings on the effects of various livestock manure types on soil fertility, soil physical properties, soil biology and the yield of various cereal crops. Specifically, this paper summarizes results for poultry, cattle, and swine manure used in various cropping systems. Although there are conflicting results in the literature with regards to the effect of manure on various soil properties, the literature offers convincing evidence of beneficial impacts of manure on soil and the growth of crops. The degree to which manure affects soil depends on the physical and chemical properties of the manure itself and various management and environmental factors including rate and timing of application, soil type, and climate.

**Keywords:** manure; soil fertility; nutrients; soil organic carbon

## 1. Introduction

Manure was applied to crops as a slow release fertilizer by European farmers as early as 6000 B.C. [1]. Since the early years of agricultural development in the United States (U.S.), the 16th through the 19th century, manure has been considered an agricultural resource of significance [2]. Early publications from the United States Department of Agriculture (USDA) showed that it was believed that the neglect of this resource would lead to significant losses for the farm [3]. In these records, the fertilizing value of manure produced by the number of cattle in the U.S. at that time was estimated to be over 1 billion U.S. dollars [3]. These early records indicate that the USDA worked to increase the awareness of the nutrient value of manure among farmers. It also sought to encourage farmers to use manure rather than completely replacing it with commercial fertilizers. Economic and demographic developments after the second world war brought about an increase in agricultural production efficiency which resulted in the rise of large concentrations of livestock operations at the same time that commercial fertilizer production was also increasing [2]. In today's world, land degradation as a result of erosion, desertification, tillage, and unsustainable agricultural practices have caused a significant decline in productivity on some land [4]. On the other hand, the growth in world population has increased food demand, which requires an increase in agricultural production. These developments necessitate the implementation of practices that improve or restore the quality of agricultural land. Manure has been known to have beneficial effects on soil fertility and many other soil properties, contributing to the overall soil health. The Natural Resources Conservation Service (NRCS) defined soil health or

soil quality as the continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans [5]. One of the reasons that there has been an increasing interest in the use of organic nutrient sources and soil amendments is the fact that they are a source of carbon (C) which plays a role in improving soil quality and climate change mitigation. Heightened public and consumer's interest in organically produced crops and sustainable agriculture have also contributed to an increasing demand in organic soil amendments [6,7]. Sources of animal manure that are most used in the U.S. are cattle and chicken manure [8]. However, the use of other livestock manure such as horse, sheep, goat, turkey, and rabbit among others are not uncommon around the world. The USEPA (2013) [9] estimated that 900 million Mg of manure was generated from 2.2 billion livestock in 2007. In 2012, manure was applied to 275,000 farms translating to roughly 8.9 million hectares of cropland in the U.S. [10]. In an analysis of global data, Zhang et al. [11] showed a steady increase in manure nitrogen (N) production, globally, between 1998 and 2014 to 131 Tg N yr<sup>-1</sup>. This study also showed that on a global scale, cattle contributed the most to global manure N production, contributing 43.7% to the total manure N production in 2014, while goats and sheep together produced one third of the global manure N in that same year [12]. More recent statistics published by the FAO [8] show that globally, most manure N applied to cropland came from poultry (chicken, duck, and turkey); contributing  $7132 \times 10^3$  Mg of N to cropland (Figure 1). From these data we can infer that manure remains an important source of nutrients in agricultural production. Ultimately, the amount of manure applied to fields depends on different factors including the composition of the manure, the soil available nutrients, the crop to be grown, and environmental conditions [13]. The objective of this paper is to compile the existing research related to the effects of poultry, cattle, and swine manure on overall soil health. In this paper we approach soil health as consisting of a set of independent indicators, what Kibblewhite et al. [14] calls the “reductionist” approach. We consider various chemical, physical, and biological properties of the soil which all contribute to overall soil health. In addition, we evaluate the effect of these manure types on the yields in various grain cropping systems.

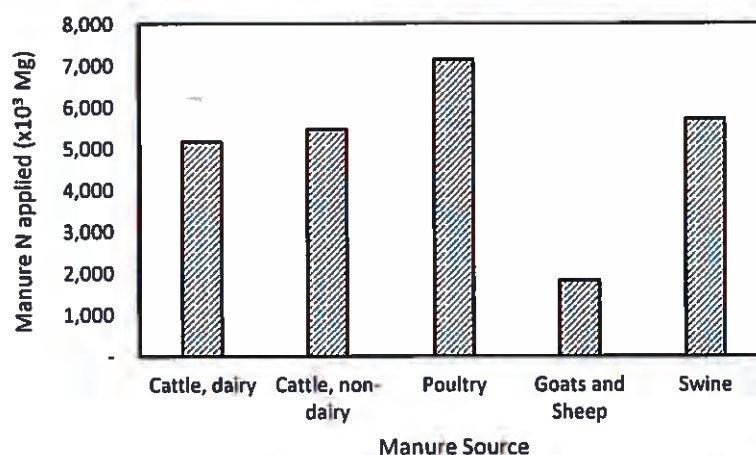


Figure 1. The nitrogen (N) applied to global land as manure coming from different livestock (Source: Food and Agriculture Organization (FAO, [8])).

## 2. Methodology

Several procedures and criteria were followed to put together this comprehensive review of literature. Firstly, the manure types that are most used on a global scale were identified. These manure types included cattle, poultry, and swine manure. Web search engines such as Google and Google Scholar™ were then used to find peer reviewed journal articles related to these manure types. Soil health indicators as defined by the NRCS [5] were listed and used to further narrow down the search and organize the studies in four main categories: soil chemical properties, soil physical properties, soil biological properties, and grain yield. When considering yield, this work focused solely on yield

components in cereal grain crops, as these are the most widely grown crops globally [8]. These web searches were supplemented by studies accessed through the academic databases Agricola and Web of Science. Publications were also accessed through organizational websites such as USDA-NRCS, FAO, and the Soil Science Society of America. A wide range of studies were included in this review, including field, greenhouse, and laboratory studies. The studies were selected based on the following criteria: (1) they evaluated the effect of poultry, cattle manure, or swine manure on one or various soil properties; studies where the animal source of the manure was not clearly defined were not included; (2) they evaluated raw or composted manure; (3) they included at least two growth cycles or cropping seasons, or multiple study sites; (4) they reported numerical results and statistical analysis of the data.

Data from a total of 130 studies were included in this review. Data organization and visualization for this review was done using Microsoft® Excel.

### 3. Soil Nutrient Status

Soil fertility is defined as the available nutrient status of the soil and its ability to provide nutrients inherently and from external sources [15]. Various studies have reported an increase in macro- and micronutrients as a result of manure application [16–18], which in turn positively affects the growth and productivity of crops. Various chemical properties influence the overall fertility of soils including soil pH, cation exchange capacity (CEC), organic matter, and organic carbon (C). Manure application affects these different soil properties in addition to releasing nutrients through mineralization. The nutrient content of manure depends on several factors including animal type (Table 1), feed intake and water consumption by the animals [7], manure storage and management, and whether the manure is liquid or solid [19]. This section of the paper explores the effect of land applied manure on soil chemical properties, including selected nutrients and their availability.

**Table 1.** Total nitrogen (N), phosphorus ( $P_2O_5$ ), and potassium ( $K_2O$ ) concentrations in various manure types as reported in literature.

Manure Type	Total N	$P_2O_5$	$K_2O$	Reference
	g kg <sup>-1</sup>			
Beef	3.7 (liquid) †	0.8	2.3	[20]
	5.5 (solid) † §	9	5	[21]
	10.5 (solid) † ¶	9	13	
	3.8 (1000-lbs. cow) †	2.0	3.2	[22]
	22.8 ‡	5.2	21.5	[23]
Dairy	3.9 (liquid) †	0.9	2.5	[20]
	5.5 (solid)	2.5	5.5	[24]
	4.5 (solid) † §	2	5	[21]
	12 (liquid) †	9	14.5	
	5.9 (1000-lbs dry cow) †	2.2	4.7	[22]
	3.3–8.8 (solid)	1.1–8.8	1.1–17.6	[25]
Swine	3.9 (solid) †	1.2	1.3	[20]
	5 (solid) † §	4.5	4	[21]
	4 (solid) † §	3.5	3.5	
	11.5 (300 lbs. finishing)	4.1	6.1	[22]
	2.2–15.4	1.1–34.2	1.1–9.9	[25]
Poultry	8.1 †	2.8	3.0	[20]
	16.5 (solid) † §	24	17	[21]
	28 (solid) † ¶	22.5	17	
	11.0 (broiler)	7.4	5.3	[22]
	19.3	28.9	14.7	[26]

† As-is basis, ‡ Dry weight; § No bedding or litter; ¶ Bedding or litter.

#### 4. Total Nitrogen and Nitrate

Various studies have evaluated the effect of manure on total N [26,27] and nitrate [28] in the soil. The studies evaluated for this review show a general increase in soil total N, as the rate of manure increased (Table 2). However, work by Ferreras et al. [29] showed that an increase in the rate of manure from 10 to 20 Mg ha<sup>-1</sup> did not increase soil N. In a study, investigating the effect of dairy manure and tillage in maize, Khan et al. [30] reported that the addition of 10 Mg ha<sup>-1</sup> and 20 Mg ha<sup>-1</sup> of dairy manure in addition to inorganic fertilizer increased soil N by 24% and 27%, respectively, compared to inorganic fertilizer alone. The release of N or any other nutrient from manure depends on the rate of mineralization. In general, the amount of a nutrient that is mineralized in manure is a function of manure characteristics, environmental factors, soil properties, and microbial activity [13]. Eghball et al. [13] also noted that manures containing large amounts of organic N release less plant-available N, since the organic N needs to be converted to inorganic N first. A study conducted by Hou et al. [31] showed that the application of chicken manure in combination with inorganic fertilizer significantly increased the N content in plant parts. Conversely, manure application has been associated with increased nitrate (NO<sub>3</sub>) leaching from soils [32]. Application of manure at a time when the plant does not absorb N can cause significant losses of nitrate, especially during high rainfall events. Various studies have evaluated nitrate leaching from manure [32,33]. Van Es et al. [33] confirmed that timing of manure application and soil type affected the amount of nitrate concentration in drainage waters; manure applications made in late fall reduced the concentration of nitrate N concentration by 4 mg L<sup>-1</sup> relative to early fall applications made in maize. This study showed that the lowest nitrate N concentrations were achieved with spring applications. The dependence on environmental factors such as moisture and temperature and the potential losses make the availability of N from manure highly variable and unpredictable. As a result, producers often over apply manure to land which in turn becomes a potential problem to the environment. The studies that were reviewed showed a general increase in total N with increase in the rate of manure applied (Table 2), however, this increase was not consistent across all studies. A study by Mokgolo [34] showed that the addition of 20 Mg per ha produced a slight reduction or no change in total N. A study by Adeli et al. [35] however, showed that the application of 2.2 Mg of manure per ha increased the total soil N by 110 mg kg<sup>-1</sup>; doubling the application to about 4.5 Mg ha<sup>-1</sup> increased soil N by an additional 30 mg kg<sup>-1</sup> relative to the control. Another study showed that increasing the poultry manure application rate from 5 to 10 Mg per ha did not cause a significant increase in total soil N [26] (Table 2). These findings confirm the unpredictability of the release of nutrients from manure.

**Table 2.** A review of total nitrogen (N), soil test P, and exchangeable potassium (K), relative to the control treatments (no manure and no fertilizer) as a function of manure application.

Study Site	Nutrient		Total N	Soil Test P	Exchangeable K	References
	Source	Quantity Mg ha <sup>-1</sup>		mg kg <sup>-1</sup>		
South Africa	-	0	450, 570 †	7.6, 2.0	156, 163.8	[34]
	Poultry	20	420, 570	9.3, 2.7	252.3, 417.3	
	Cattle	20	500, 650	31.0, 30.3	250.8, 265.2	
	Poultry + Cattle	20 + 20	370, 780	8.5, 29.4	223.1, 553.8	
United States	-	0	650, 600 †	22, 55		[35]
	Poultry	2.2	860, 700	38, 97		
	Poultry	4.5	890, 770	64, 119		
	Poultry	6.7	980, 890	97, 146		
China	-	0	980	5.8	144	[36]
	Cattle	75	1220	12.7	193	



Table 2. Cont.

Study Site	Nutrient	Total N	Soil Test P	Exchangeable K	References
	Source	Quantity Mg ha <sup>-1</sup>	mg kg <sup>-1</sup>		
Nigeria	-	0	900,1100 ‡	8.3, 9.9	[37]
	Poultry	7.5	3100, 3600 ‡	13.5, 15.4	
Nigeria	-	0	600	9.1, 6.9	[26]
	Poultry	5	800,700 †	12.5, 14.2	
	Poultry	10	900,800	13.2, 17.8	
Nigeria	-	0	900, 1200 †	10.6, 9.0	[38]
	Poultry	10	1700, 3500	18.2, 18.9	
	Poultry	25	5100, 4800	30.9, 37.1	
	Poultry	40	2800, 5200	33.0, 44.3	
	Poultry	50	3100, 5600	32.6, 45.6	
Argentina	-	0	950, 1240 †		[29]
	Poultry	10	1050, 1550		
	Poultry	20	1080, 1490		
United States	-	0		51.8, 65.3 §	[23]
	Cattle	10		93.6, 101.3	
	Cattle	20		153.6, 162.8	
	Cattle	30		205.7, 155.4	
	Cattle	40		236.1, 209.3	
Canada	-	0	1300		[39]
	Cattle	20	1400		
	Cattle	40	1500		
	Cattle	60	1600		

† numbers separated by a comma indicate the numbers in different years or seasons at a single location; ‡ numbers separated by a comma indicate the numbers at two different locations averaged over multiple years; § numbers separated by a comma indicate the soil nutrient content immediately after manure application and 8 weeks after incubation.

## 5. Phosphorus

Repeated manure applications can lead to excessive P levels in soil [40]. One of the additional challenges this brings, is the potential for phosphorus (P) runoff causing eutrophication in surface waters. Manure contains both organic and inorganic P. The inorganic orthophosphates are the form in which P is taken up by plants and it generally constitutes 45% to 90% of the P in manure [41], making manure an important source of P. However, the problem of excessive P in soils to which manure has been applied is caused by the narrow N: P ratios in manure relative to the N: P ratio in plants [41]. This means that manure needs be applied in large amounts to supply the N required by plants. As the crop removes more N than P from the manure, P build-up is inevitable [40]. A study conducted by Butler et al. [42] showed a 10-fold increase in soil-P with the addition of 70 Mg ha<sup>-1</sup> of composted dairy manure relative to the treatment with no compost application. The literature generally shows a linear increase in available phosphorus (P) with an increase in the amount of manure applied to soil (Table 2). The increase in available P after manure application to soil is a function of various soil characteristics including soil pH, organic matter content, and clay type [43]. The nutrient content and thus the P content of manure can be highly variable and depends on animal species, diet composition, manure storage, type of bedding, and moisture content [44]. Barnett [45] noted the importance of not just knowing the total P content, because the value of manure for use as a fertilizer hinges on P that is plant available. In addition to soil properties, manure characteristics also affect

the portion of P that becomes plant available. There are various forms of extractable P in manure, herein arranged in decreasing order of plant availability: (1) water soluble, (2) bicarbonate-extractable P, (3) sorbed P that is soluble in sodium hydroxide, and (4) acid extractable P [31]. Swine and poultry manure have been shown to have higher concentrations of total P, while dairy manure contains the highest amount of water-soluble P. Fuentes et al. [44] noted that the factor that affects the manure P content the most is the form in which P is provided in feed. Phytic acid is the main form of P in cereal grains [46]. Swine and poultry manure generally contain more phytic P than cattle manure. The reason is that chicken and swine contain less phytase to break down phytic acid than cattle does [41,44]. Phytic P, unlike phosphate, easily forms insoluble complexes in soil, making it less plant available and susceptible to loss through runoff [46].

## 6. Trace Elements and Micronutrients

Various works have reported on the effect of applied manure on trace elements in soil [47–49]. Trace elements are defined as microelements with a concentration of less than  $100 \text{ mg kg}^{-1}$  on average [50]. Some of these trace elements are essential for the growth and productivity of plants and animals; these are called micronutrients [51]. Work by Nikoli and Matsi [48] has shown that micronutrient availability increases with manure application. In this study, it was shown that after nine years of manure application, extractable Cu, Zn, Mn, and B significantly increased relative to the control and inorganic nutrient treatments. Japenga et al. [52] postulated that adding liquid manure to soil aids in solubilization of metal micronutrients. This can be attributed to the formation of water-soluble complexes between organic ligands and the metal micronutrients [53,54]. A study conducted by Sheppard and Sanipelli [49], in which various manure types were tested for approximately 60 different elements, showed an accumulation of trace elements, but primarily Zn, in manured soils. The accumulation of trace elements was correlated with P accumulation in those soils. Similarly, work by Benke et al. [47] found that long-term manure application increased total Cu and Zn in the soil, with significantly elevated levels for Zn in the topsoil after application of  $180 \text{ Mg ha}^{-1}$  manure. In a study conducted by Sager [55] the highest concentrations of Zn were found in pig manure relative to cattle manure, pig dung, poultry dung, biogas manure, compost, and sewage sludge at nearly  $1200 \text{ mg kg}^{-1}$ . These levels of Zn in manure would qualify this as hazardous waste based on Austrian standards [55]. Research has established that as with other nutrients, trace elements in manure are strongly related to the trace elements in animal feed [49,56]. These findings are further confirmed by Chaudhary and Narpal [57] who found that DTPA extractable Zn, Fe, Mn, and Cu increased with increasing rate of farmyard manure. The increase of these elements with increasing rates of manure is likely due to the formation of complexes with organic ligands, preventing them from being adsorbed to the soil complex or precipitating out of soil solution [57].

## 7. Soil Acidity

The literature shows an inconsistent relationship between manure and the soil pH. The literature is replete with works that show an increase in pH as a function manure application [58–60]. Ano and Ubochi [59] reported a consistent increase in soil pH with the application of 10, 20, 30, and  $40 \text{ Mg ha}^{-1}$  of rabbit, swine, goat, chicken, and cow manures. The increase in the pH as a function of manure application has been attributed to the calcium carbonate and bicarbonate found in manure [23,61], the addition of cations such as Ca and Mg [62], and the presence of organic anions in the manure which can neutralize  $\text{H}^+$  ions [63]. The presence of these substances in the manure depends on the animal diet. Narambuye and Haynes [64] found that manure types with elevated levels of  $\text{CaCO}_3$  increased the pH to a greater degree in comparison to manure with lower levels of  $\text{CaCO}_3$ ; poultry and pig manure had higher levels of  $\text{CaCO}_3$  relative to cattle manure because of their  $\text{CaCO}_3$  rich diet in comparison to an all grass diet for the cattle. This study also showed that increasing  $\text{CaCO}_3$  resulted in increasing proton consumption capacity for the different manure types tested and that as pH increased  $\text{Al}^{3+}$  in solution decreased. In contrast, Hao and Chang [65] found a steady decrease in the soil pH with increasing

rate of cattle manure application under irrigated and non-irrigated growing conditions. In a study evaluating chemical changes in soil as a result of cattle feedlot manure applications, Chang et al. [66] found a decrease of 0.3–0.7 in the soil pH over an 11-year period of manure application. Similarly, O'Hallorans et al. [58] found a linear decrease with an increasing rate of chicken manure. The decrease in soil pH is explained by the acidifying effect of nitrification and the concomitant increase in electrical conductivity; the increase in cations replace  $H^+$  ions on the exchange sites [58]. Tang and Yu [67] found that the concentration of organic anions, the initial soil pH, and the degree of residue composition effect the degree of acidification of soil by organic residues. A long-term study by N'dayegamiye and Cote [39] showed that there was no increase or decrease in the soil pH as a function of farmyard manure or pig slurry. This was attributed to the fact that this soil had been limed before the experiment. The variability in results show that the effect of manure on soil acidity depends on the properties of the manure type and the soil conditions [60].

## 8. Cation Exchange Capacity and Ca, Mg Saturation

Cation exchange capacity (CEC) is a measure of the retention of positively charged ions on the surface of soil particles [68]. The CEC of soil generally increases with the increase of clay content and organic matter. Studies have shown that there is an increasing trend in the CEC with an increase in the rate of applied manure (Table 3). This trend can be attributed to the organic matter in manure and the increasing pH with manure application [69]. A study by Steiner et al. [27] showed that the application of chicken manure at  $47 \text{ Mg ha}^{-1}$  organic matter content increased the CEC by more than  $10 \text{ cmol kg}^{-1}$ , with significantly higher concentrations of base cations in comparison to the control plots. Furthermore, Miller et al. [70] found a significant linear relationship between the rate of manure application and the CEC after 13 years of application, while no significant relationship was found after just one year of application. However, this increase is not consistent across all the studies evaluated for this review. Mokgolo [34] found a decrease of  $4.67 \text{ cmol kg}^{-1}$  in the CEC with the application of  $20 \text{ Mg ha}^{-1}$  of manure relative to the control, which was consistent with a decrease in the exchangeable Ca and Mg (Table 3). Another study, evaluating the effect of long-term manure application on CEC, found that applying cattle manure at  $90 \text{ Mg ha}^{-1}$  increased the CEC by  $5.6 \text{ cmol kg}^{-1}$  under non-irrigated conditions. Under irrigation the application of the same rate of manure increased the CEC from  $19.6 \text{ cmol kg}^{-1}$  to  $33.5 \text{ cmol kg}^{-1}$  [65]. The concentration of extractable Ca, Mg, and Na were lower in the poultry manure treated plots relative to the control treatment. In addition, this study showed an increase of the CEC with the application of cow manure. A possible explanation is that the chicken manure had a higher C/N ratio relative to the cow manure. The higher C/N ratio reduced the rate of decomposition and therefore the CEC. Miller et al. [70] postulated that decomposition of organic matter increases the CEC due to an increase in the negatively charged sites on carboxyl and phenolic groups. Similarly, Muller [71] noted that the CEC of plant residue is closely related to the degree of decomposition of organic residue.

**Table 3.** A review of cation exchange capacity (CEC), exchangeable potassium (K), calcium (Ca), and magnesium (Mg) relative to the control treatment as a function of manure application.

Study Site	Nutrient	CEC	Ca	Mg	References
	Source	Quantity $\text{Mg ha}^{-1}$	$\text{Cmol kg}^{-1}$		
South Africa	-	0	18.2, 17.7 †	6.7, 7.2 †	[34]
	Poultry	20	13.5, 15.6	5.5, 6.3	
	Cattle	20	19.1, 21.0	8.5, 8.7	
	Poultry + Cattle	20 + 20	16.1, 17.2	5.6, 7.5	

Table 3. Cont.

Study Site	Nutrient	CEC	Ca	Mg	References
	Source	Quantity Mg ha <sup>-1</sup>	Cmol kg <sup>-1</sup>		
Canada	-	0	25.2, 25.0, 27.3 †		[70]
	Cattle ¶	13	25.9, 26.6, 28.7		
	Cattle	39	26.7, 26.7, 29.8		
	Cattle	77	26.8, 28.4, 31.6		
	Cattle ¶¶	13	26.5, 25.5, 28.5		
		39	25.4, 27.2, 29.1		
		77	27.2, 25.9, 30.2		
Nigeria	-	0	2.0, 1.2 ‡	0.9, 1.3 ‡	[37]
	Poultry	7.5	3.7, 3.5 ‡	2.5, 2.1 ‡	
Nigeria	-	0	2.8, 3.6 †	2.1, 2.1 †	[26]
	Poultry	5	4.0, 4.9	2.8, 3.0	
	Poultry	10	4.5, 6.6	2.6, 4.2	
Canada	-	0	19.5, 19.6 §	15.4, 15.8 §	[65]
	Cattle	30	20.7, 23.7	13.7, 16.1	
	Cattle	60	24.2, 28.4	15.0, 19.0	
	Cattle	90	25.1, 33.5	14.5, 21.3	
Canada	-	0	16.1	6.5	[72]
	Cattle	100 £	16.5	6.6	
	Cattle	400 £	18.0	6.7	
Puerto Rico	-	0	1.7	0.5	[58]
	Poultry	5	1.8	0.5	
	Poultry	10	2.0	0.5	
	Poultry	15	2.4	0.6	

† numbers separated by a comma indicate the numbers in different years or seasons at a single location; ‡ numbers separated by a comma indicate the numbers at different locations averaged over multiple years; § numbers separated by a comma indicate the numbers under two different growing conditions non-irrigated and irrigated, respectively; ¶ composted manure with straw; ¶¶ stockpiled manure with straw; £ Presented as kg N ha<sup>-1</sup>.

## 9. Electrical Conductivity

Electrical conductivity (EC) is the ability of a substance to conduct an electrical current [73]. When the effect of manure on soil EC was considered, literature showed that increasing manure application increases EC. Soil EC is related to various soil properties such as organic matter content, texture, moisture content, salinity, and CEC [74]. Electrical conductivity in soil has been primarily linked to exchangeable K<sup>+</sup> [58,75,76]. Work by O'Hallorans et al. [58] showed a linear increase in the EC with the increase in the rate of manure applied. This work reported an increase of 1.73 mmho cm<sup>-1</sup> with the application of 15 Mg ha<sup>-1</sup> of chicken manure relative to the treatment without any manure. The experimental design of this study, conducted in Puerto Rico, was a randomized complete block design in a split plot arrangement. Main plots consisted of 4 N rates and subplots contained 4 chicken manure rates: 0, 5, 10, and 15 Mg ha<sup>-1</sup>. The increasing EC with increasing manure application makes sense as it can be related to increasing organic matter, which supplies a pool of nutrients and ions that can be released in the soil solution [77]. Similar to the findings by O'Hallorans et al. [58], Miller et al. [78] found an increase in EC with increasing rate of beef manure. The study showed that treatments where 77 Mg ha<sup>-1</sup> of stockpiled manure with straw had been applied, the EC increased to 7 mmho cm<sup>-1</sup>, while the unamended treatment had an EC of 0.8 mmho cm<sup>-1</sup>. The study compared manure with straw bedding to manure with woodchips and found that woodchips were better for



keeping the EC below levels that would inhibit growth of the most common crops ( $<4 \text{ mmho cm}^{-1}$ ). It is interesting to note that straw as bedding also produced higher concentrations of soluble cations and anions in the surface soil, which correlates to the higher EC with manure containing straw bedding. These results imply that the effect of manure on EC is highly dependent on the rate and type of manure and the type of bedding used.

## 10. Soil Organic Matter and Carbon

One of the biggest challenges in soil health is the depletion of soil organic matter (SOM) as a result of long-term cultivation of land [79]. Studies have shown, however, that the addition of animal manures to soil increases SOM or retards the process of SOM depletion [80,81]. The studies used in this review consistently show an increase in SOM with manure application. In a tomato study, Ewulo et al. [38] found that with the application of 10, 25, 40, and 50 Mg chicken manure per hectare (ha), SOM levels respectively increased by 0.85, 1.50, 1.72, and 1.95 percentage points relative to the control treatment with no addition of manure. These findings agree with work by Deryqe et al. [82] who found that applying chicken manure at rates of 5, 10, and 15 Mg ha<sup>-1</sup> increased SOM by 0.44, 0.96, and 1.68 percentage points, respectively. Similar results are found with the addition of cow manure to soil. In one year of a three-year study conducted by Butler et al. [42], the addition of 35 Mg ha<sup>-1</sup> dairy manure compost significantly increased SOM by 8.7 g kg<sup>-1</sup> which represented an increase of 73% relative to the untreated check (Table 4). There was no difference in the SOM content with the higher rates of applied compost. The study was conducted over 3 years and evaluated the effect of dairy manure compost on silage quality and soil properties. Manure compost was applied only in the first year of the study, as a result SOM kept decreasing in consecutive years. This shows that the addition of manure slows down the depletion of SOM.

Table 4. Effects of Dairy Manure on Organic Matter (Adapted from (Butler et al. [42])).

Treatment	Organic Matter (g kg <sup>-1</sup> )
Untreated check	12.0
Inorganic fertilizer (336N-49P-93K kg ha <sup>-1</sup> )	14.8
Dairy Compost (Mg ha <sup>-1</sup> )	
0	15.6
35	20.7
70	29.3
105	29.3

The buildup of SOM as a function of manure application depends greatly on the manure type and the type of manure bedding [83,84]. Manure that contains bedding high in organic matter will produce a greater increase in SOM compared to manure with low organic matter bedding [84]. The benefits of building or maintaining SOM are many; some of which are reduced erosion and runoff [85], improved infiltration [86], improved soil structure [87]. One aspect that is receiving much attention is the contribution of organic amendments to the carbon (C) cycle [88,89]. Various works have stressed the importance of soil organic carbon (SOC) in mitigating the impacts of climate change [90,91]. There is great disparity in what has been reported in the literature on the relationship between manure and SOC. In an evaluation and analysis of the cattle manure studies included in this review that reported on SOC, no significant relationship was found between the cattle manure rate and SOC (Figure 2). The poor relationship illustrates the conflicting results found in literature when it comes to the relationship between manure and SOC. In a report by the World Bank [92] it was estimated that in Africa, Asia, and Latin America, carbon sequestration rates were, respectively, 23%, 109%, and 267% higher on soils where manure had been applied compared to soils treated with inorganic fertilizer. Liu et al. [36] found that in comparison to the control and inorganic fertilizer treatments,



the addition of farmyard manure to soil alone and in combination with N and P resulted in higher SOC contents of  $9.98 \text{ g kg}^{-1}$  and  $10.52 \text{ g kg}^{-1}$ , respectively. A study by Wang et al. [93] showed that over a 23-year period, pig manure alone and in combination with N, P, and K increased SOC by 25% and 30% relative to the treatment without any additional fertilizer or manure. In contrast, this study showed that where no nutrients had been applied, initial SOC decreased by 9% in the top 20 cm of soil. Consistent with these findings, Manna et al. [94] showed that SOC in unfertilized plots declined by at least 15.5%, whereas SOC was either maintained or increased with the addition of fertilizer and manure relative to initial levels. Other research has shown, however, that the addition of manure to soil over multiple years decreased SOC, but at a slower rate than in unfertilized plots [95]. These results are consistent with work by Ren et al. [96], who reported that the addition of manure did not increase SOC. Tan et al. [97] postulated that the dynamics of SOC can be somewhat explained by studying the way C is allocated in the different fractions of soil organic matter. The light fraction of SOM is defined as a fraction that is sensitive to changes in management practices [97,98] and shows a high correlation with N mineralization [97,99,100]. Microbes decompose organic matter, using the carbon as source of energy, and release nutrients into the soil. Increased microbial respiration because of the addition of organic matter can be indicated as the source of the decrease in SOC [101] as found in some studies.

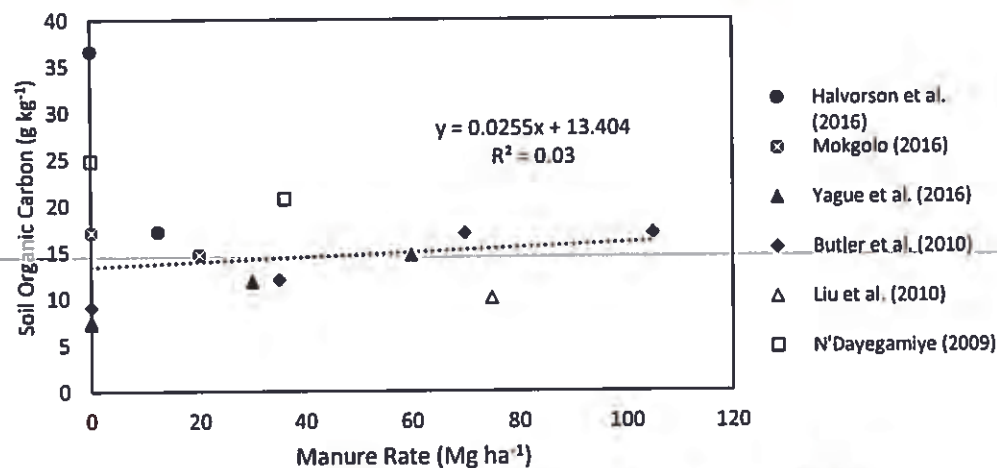


Figure 2. Relationship between cattle manure and soil organic carbon (SOC). Included in this dataset are six different studies evaluating the relationship between cattle manure and soil properties.

## 11. Manure and Soil Physical Properties

The addition of manure to soils in general does not only impact soil chemical properties but it also greatly impacts soil physical conditions such as soil water [86,102], structure [86], bulk density [102], and resistance against erosion [103,104]. In this section we specifically focus on the effects of manure on soil water, soil temperature, and bulk density.

## 12. Soil Water and Soil Hydraulic Properties

One of the challenges we face in agriculture is the scarcity of water [105]. According to Mekonnen and Hoekstra [106], an estimated 4 billion people live with severe water scarcity at least one month out of the year. With the growing world population and the increase in food demand, the pressure on this already scarce resource will only increase. One of the ways to mitigate this problem is to increase on-farm water retention which can be accomplished by applying organic soil amendments to land. Various studies have shown a relationship between SOM and water infiltration, soil water holding capacity, or water content [103,107,108]. Organic matter promotes soil aggregation which allows the formation of pores and thus storage of water [109]. The effect of organic matter on soil water retention has been documented extensively and conclusions vary [110–114]. Minasny and

McBratney [111] showed a small increase in soil water with increase in organic C, but they argued that rate of organic C sequestration and the presumed increase in available water did not correspond and was negligible. However, other works have shown a significant effect of organic matter on the retention of water [110,112–114]. Ankenbauer et al. [112] found that the effect of organic matter on water retention was more profound on low clay content soil. Other work has shown that organic matter increases the soil's adsorbing capacity allowing for improved water retention [113]. Various properties of the organic matter itself, however, may contribute to the increase in soil water retention. In a study evaluating hydraulic properties of biochar amended soil, Ni et al. [114] found that field capacity, permanent wilting point, and available water content increased by 38%, 58%, and 14%, respectively, relative to bare soil. In addition, field capacity and permanent wilting point increased by 43% and 57%, respectively, when biochar was added to grass covered soil. This work noted that the pores inside biochar might have acted as additional capillaries allowing for increased water storage. Soil water holding capacity or available water capacity is the amount of water that a soil can hold for use by plants; it is the water that is held between field capacity and permanent wilting point [115]. The water content of a soil is defined as the total amount of water present in the soil and is expressed as gravimetric or volumetric water content [116]. The volumetric water content can be calculated by multiplying the mass water content by the ratio of the bulk density and the density of water [117]. The literature shows varying results pertaining to the effect of manure on soil water content. In a study evaluating the effect of feedlot manure on various soil physical properties, Miller et al. [118] found little to no significant difference in soil volumetric water content based on manure type and bedding in the surface (0–5.5 cm) soil over two years of the study. However, Ahmed et al. [119] found that soil treated with poultry or farmyard manure retained more water than untreated soil. Similarly, Nyamangara et al. [108] found that the addition of cattle manure to soil increased water retention in comparison to the control treatment where no manure had been applied. In a study evaluating the effect of farmyard manure on soil physical and chemical parameters, Schjønning et al. [103] found a higher water retention for farmyard manure compared to NPK fertilizer and unfertilized treatments at depths of 8–12 cm and 30–35 cm. In an early study by Bouyoucos [107] it was shown that adding 54 Mg of partially decomposed horse-cow manure to a sandy loam increased the percent by volume soil water content by 10.2 percentage points relative to the plots where no manure had been applied. In more recent published work by Wang et al. [120] it was shown that the application of 15 Mg ha<sup>-1</sup> and 22.5 Mg ha<sup>-1</sup> significantly increased soil water storage at the tasseling stage of maize in comparison to lower rates of manure and synthetic fertilizer. These findings suggest that manure application affects soil water. The increase in soil water retention as a function of manure application is likely an effect of the organic matter on soil porosity. Infiltration, as a soil physical term, is defined as the process by which water enters the soil by downward flow through the soil surface [117]. When the infiltration capacity of a soil is saturated, ponding or runoff occurs [121]. This means that the more water infiltrates into the soil, the less water is lost through runoff. Yague et al. [122] showed that with manure applications, runoff was reduced by as much as 82% under no till and by 42% in plots that had been chisel plowed. Manure may impact infiltration and hydraulic conductivity due to its effect on soil aggregation [123], especially when the manure is rich in Ca and Mg ions [124].

### 13. Soil Temperature

Soil temperature and temperature fluctuations affect various soil health indicators. Soil temperature has been shown to affect soil biological activity [125,126], nutrient cycling [127] and nutrient uptake [128]. There are few works that report on the effect of manure on soil temperature. There are some studies, however, that have reported on the relationship between other organic amendments and soil temperature. In a study evaluating the effect of poultry manure on various soil properties, Agbede et al. [37] found that the addition of 7.5 Mg ha<sup>-1</sup> manure consistently decreased the soil temperature by 2 to 2.3 degrees Celsius. The lower temperatures associated with the application of organic amendments is likely caused by improved water retention and protection of the soil against large temperature

fluctuations [129]. In contrast, Deguchi et al. [130] found that soil temperature increased with increasing rates of applied compost. This increase in soil temperature was attributed to the reduced evaporation with the application of compost to the soil [130]. Similarly, Unger and Stewart [131] showed that the addition of farmyard manure resulted in a reduction in evaporation, a direct effect of manure on soil physical properties. Evaporation has a cooling effect on the soil surface, thus a reduction in evaporation suppresses the cooling of the soil surface. On the other hand, improved soil structure, increased porosity and hydraulic conductivity, resulting from manure application [12,108], could cause water to penetrate deeper into the soil causing the soil surface to dry and warm up faster [130]. In addition, the increased soil porosity due to the presence of organic matter, decreases the thermal conductivity of soil, thereby allowing the organic matter to insulate the soil against increasing temperatures during the summer [132] and warm up the soil during the winter, although its effect during the winter would be considered negligible due to the insulating effect of snow on the ground. The complexity of the relationship between manure and soil temperature is further confirmed in a study conducted by Rees et al. [133] who found that the addition of manure on potato hills with a 8% slope reduced the soil temperature by 0.32 °C relative to the control treatment, while manure on the 11% slope increased the soil temperature by 1.03 °C, from 16.16 °C to 17.19 °C. Based on these findings it becomes apparent that the effect of manure on soil temperature would be affected by the time of year, the amount of manure applied, and properties of the manure applied. Although Deguchi et al. [128] found no relationship between chemical characteristics of compost and soil temperature, the literature suggests that varying rates and characteristics of manure affect various soil physical properties including hydraulic properties which may influence soil temperature [134].

#### 14. Bulk Density

Various studies have shown a correlation between organic matter content [135,136] or organic amendments [137,138] and bulk density. Bulk density is an important indicator of soil compaction and depends on the density of mineral particles, organic matter, and their packing arrangement [139]. Bulk density is the weight of dry soil per unit bulk volume of soil, which includes solids plus pore space [115]. The more solids a soil has relative to pore space, the higher the bulk density for that soil [137]. A review by Khaleel et al. [140] showed a consistent decrease in bulk density with the application of various organic waste products in both long-term and short-term studies. Compiled data from chicken manure studies show a negative linear relationship between the rates of manure applied and soil bulk density (Figure 3). Agbede et al. [141] showed a 28% decrease in the bulk density when 30 Mg ha<sup>-1</sup> of chicken manure was applied to soil. Other studies have shown similar results. A study conducted by Celik et al. [142] showed that the addition of compost or manure at 25 Mg ha<sup>-1</sup> year<sup>-1</sup> resulted in the lowest bulk densities in comparison to synthetic fertilizer. This study found that the average bulk density at a depth of 0–15 cm was 1.21 mg m<sup>-3</sup> in plots where manure had been applied compared to 1.40 mg m<sup>-3</sup> in plots where synthetic fertilizer, N, P, and K had been applied. Ahmad et al. [7] found that a 4%, 8%, and 9% decrease in bulk density resulted from cow manure applications of 165, 335, and 670 kg N ha<sup>-1</sup>, respectively. The decrease in bulk density as a result of manure application is primarily caused by the increase in porosity. Soil porosity is the volume of space in-between soil particles that can be filled with water and/or air. In a study conducted by Meng et al. [143] results showed that long-term annual manure applications decreased the bulk density and increased the total porosity of the soil. This study showed that 20 years of manure application increased the total porosity of the soil by 11.9%, while the bulk density decreased by 13.1% relative to the control treatment. Khaleel et al. [140] called the increasing pore space with mixing in of organic waste with the denser mineral fraction of the soil, the dilution effect. Treatment of the soil with organic products such as manure release bacterial gums and polysaccharides that aid in binding soil particles together, thus increasing aggregation and decreasing the bulk density [144].

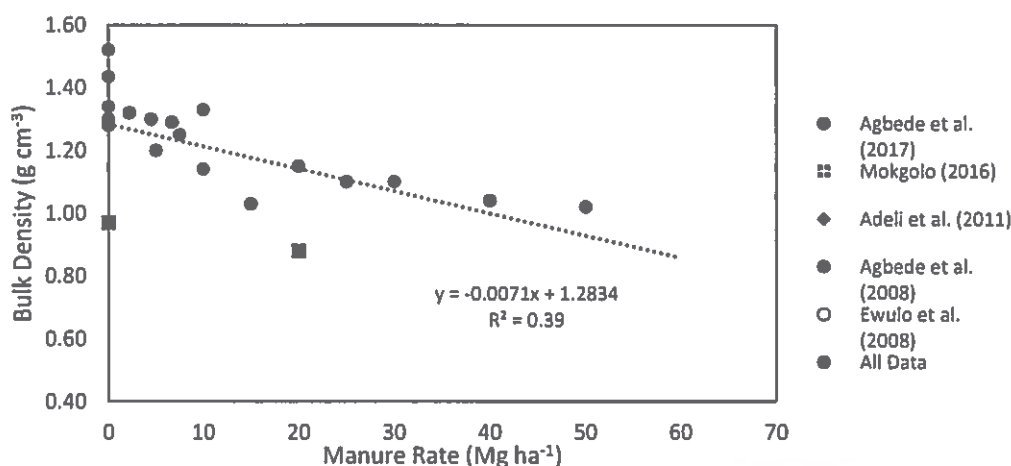


Figure 3. The relationship between the rate of chicken manure and soil bulk density as derived from data from five different studies.

## 15. Soil Biology

Improving soil health requires a holistic approach that does not only supply nutrients in adequate and balanced amounts but also enhances the soil biological system. In particular, soil microorganisms are a hallmark of soil as a living system that in some instances solely dictates the rate of reactions that takes place during nutrient cycling [145]. In this section, we reviewed the significance of livestock manure in improving soil microbial status and ultimately to improve soil fertility. In studies examining the role of manure in soil fertility, Parham et al. [146] and Hamm et al. [147] demonstrated that manure application enhances the bacterial community in the soil, thus leading to an improvement in soil productivity. Further, manure application also increases fungal diversity in the soil and when applied with inorganic fertilizers, reverses the declining microbial biodiversity trend associated with inorganic nutrients applied alone [148]. In summarizing past studies, we found manure-treated plots to have a large population of microorganisms than the unfertilized check plots (Table 5). These studies found bacteria to thrive well and grow large in population size in the soil treated with livestock manure. Because manure is capable of sustaining or slowing the rate at which soil pH declines over time [149], it is, therefore, not surprising that the bacterial community was richer and more even in manure treated plots [146]. Declining soil pH towards the strongly acidic regions begins to favor fungal population at the expense of bacterial population as their dominance wanes [146]. Regardless of the dominant microorganisms, this review demonstrates that applying manure is invaluable for improving soil fertility by increasing the population of microorganisms that are useful for nutrient transformations in the soil.

Table 5. A review of soil microbial population in manure vs check or inorganic nutrient sources.

Site of Study	Nutrient		Microbial		Reference
	Source	Quantity (Mg ha <sup>-1</sup> )	Type	Population (cfu g <sup>-1</sup> )	
Japan	-	0	Fungi	10 <sup>5</sup> (2.1–2.7) †	[150]
	Cattle manure	40	Fungi	10 <sup>5</sup> (2.3–3.2)	
	-	0	Bacteria	10 <sup>7</sup> (3.0–5.0)	
	Cattle manure	40	Bacteria	10 <sup>7</sup> (3.0–5.6)	
Israel	-	0	Fungi	1.2 × 10 <sup>4</sup>	[151]
	Cattle manure	90	Fungi	1.6 × 10 <sup>4</sup>	
	-	0	Bacteria	7.0 × 10 <sup>7</sup>	
	Cattle manure	90	Bacteria	8.3 × 10 <sup>7</sup>	



Table 5. Cont.

Site of Study	Nutrient		Microbial		Reference
	Source	Quantity (Mg ha <sup>-1</sup> )	Type	Population (cfu g <sup>-1</sup> )	
China	-	0	Bacteria	10 <sup>6</sup> (0.8, 1.5, 0.8) ‡	[152]
	Cattle manure	80	Bacteria	10 <sup>6</sup> (1.6, 4.4, 4.5)	
	-	0	Fungi	10 <sup>3</sup> (4.1, 4.1, 4.9)	
	Cattle manure	80	Fungi	10 <sup>3</sup> (3.5, 2.7, 1.5)	
	-	0	Actinomycetes	10 <sup>5</sup> (2.4, 2.0, 1.7)	
	Cattle manure	80	Actinomycetes	10 <sup>5</sup> (2.7, 6.6, 10.5)	
Canada	-	0	Heterotrophs	10 <sup>3</sup> (4, 6.2, 6.8)	[153]
	Cattle manure	120 §	Heterotrophs	10 <sup>3</sup> (1.6, 9.0, 70.0)	
	Cattle manure	240 §	Heterotrophs	10 <sup>3</sup> (1.6, 11.0, 96.0)	
	Cattle manure	480 §	Heterotrophs	10 <sup>3</sup> (4.9, 11.0, 5.7)	
	Urea	50 §	Heterotrophs	10 <sup>3</sup> (5.8, 4.7, 5.8)	
	Urea	100 §	Heterotrophs	10 <sup>3</sup> (5.1, 9.7, 1.1)	
	Urea	200 §	Heterotrophs	10 <sup>3</sup> (0.6, 6.1, 71.0)	

‡ the population presented as a range; § the numbers separated by coma within each parenthesis indicate the microbial colony forming units (cfu) in different years or seasons. The number outside the parenthesis is multiplied by the ones inside to obtain the total population size; § Presented in kg N ha<sup>-1</sup> of cattle manure.

Further, soil microorganisms contribute to the building of SOC which is an important indicator of soil quality [12]. The strong association between light fraction-C and culturable microbial count provides some evidence that soils with a large microbial population may also have more SOC [154]. This was further reiterated by Zhang et al. [12] who found SOC to be related to soil microbial C. As a result, applying livestock manure to the soil provides a mechanism for improving soil microbial status as well as SOC.

The increase in microbial population due to manure application is also vital for improved nutrient uptake [148,155,156]. N'dayegamiye and Cote [39] indicated that increased microbial population associated with manure application also led to an increase in potentially mineralizable N. In the same study, the authors found potentially mineralizable N to be larger at high manure application rates and that a strong association exists between organic matter and microbial activity and N mineralization potential. Because of this, nutrient availability for crop uptake may be increased due to livestock manure application to agricultural croplands. Further, fungi increase root surface area for extraction and absorption of plant nutrients [157]. This is evidenced by increased mycorrhizal colonization of crop roots in manure treatment [155,158]. This is particularly relevant in the uptake of immobile nutrients such as phosphorus (P). Bolan [159] summarized and stated that improved uptake of immobile P by plants is aided by several mechanisms undertaken together with mycorrhizal fungi including fungal hyphal root extension for nutrient extraction from a large volume of soil, quick movement of P into the fungal hyphae and solubilization of soil P. Clearly, these illustrate that applying livestock manure does not only improve microbial population but also nutrient uptake from the soil. Therefore, creating conditions favorable for increased microbial activities are vital for sustaining and improving soil fertility levels. Manure is one option that makes it possible to improve microbial activities in the soil, a point which was reiterated by Parham et al. [146] in a cattle manure study.

Aggregate stability is another attribute important for the health and productivity of the soil through its ability to hold soil particles together and to provide sites and pores for nutrient exchange. It can be debated whether microorganisms are a critical part of this soil stability. Fungal mycelia help to improve the stability of soil aggregates [160], and any action that increases the fungal population may improve aggregate stability. For example, cattle manure appears to increase the proportion of macroaggregates in the soil [161]. At the same time, the macroaggregate formation is associated with microbial biomass C indicating that applying manure leads to an improvement in microbial population and activities which subsequently improve soil aggregate stability [161]. Noteworthy is

that soil microbial activities and biomass C tend to be higher in cattle manure treatments [162]. Plaza et al. [163] corroborated this assertion in a pig slurry study and concluded that adding manure is beneficial in improving soil microbial biomass C. Since SOC serves as a binding agent for aggregate stability [164], applying manure improves this process through several ways including its ability to enhance microbial biomass. Soil that receives manure input is likely to maintain a high population of microorganisms that stabilize the soil. In fact, applying fungicide and bactericide has a reverse effect of lowering the population of bacteria and fungi. This was reported by Tang et al. [165] who observed a lower population of soil fungi and bacteria following the application of fungicide and bactericide. Since bacteria and fungi are vital in soil aggregate stability, their reduced presence due to fungicide or bactericide may lower the formation of stable soil aggregates. Despite all these positive aspects of livestock manure for soil fertility improvement, incorrect use of manure such as excess application can lead to unintended consequences. Phosphorus eutrophication, as well as leaching, denitrification and volatilization of N to water bodies and atmosphere, have all been reported in livestock manure studies [166,167].

Therefore, the use of livestock manure alongside other agronomic practices in a manner that does not negatively impact the environment is critical to improving soil biological properties which directly or indirectly also influence other soil properties.

## 16. Yield and Yield Components

Healthy soil, by definition, supports increased plant growth and productivity. Plant genetics, climatic factors, soil type and properties, and management are some factors that affect crop yield. The improvement of soil properties due to manure application may also favor crop growth and productivity. Literature is replete with evidence of the positive effect that manure has on grain yield and various yield parameters such as 1000-grain weight, biomass, and harvest index (Table 6). In a study where the effect of poultry manure on maize performance was evaluated, Adeyemo et al. [168] found that relative to the control treatment, the application of 6 Mg ha<sup>-1</sup> increased dry shoot biomass weight by 36% on a sandy clay loam and by 86% on a clay loam. This study also showed an increase in 1000-grain weight and cob weight with increasing manure application rate [168]. In contrast, Khan et al. [30] found a decrease in total dry matter yield in maize after application of 10 Mg of dairy manure per ha and a decline of 2.7 Mg ha<sup>-1</sup> dry matter relative to the N,P, and K treatment with an application of 20 Mg ha<sup>-1</sup>. In addition, this study found that manure application decreased the 1000-grain weight of maize, while no significant difference in grain yield was observed. The lack of a difference in grain yield may have been due to optimum availability of nutrients from the nutrient sources supplied. Mahmood et al. [169] found that 13 Mg of farmyard manure per ha<sup>-1</sup> decreased maize grain yield by 1.4 Mg ha<sup>-1</sup> relative to NPK at 250-150-125 kg ha<sup>-1</sup>. This is likely a result of the lower N, P, and K content in the manure that was used relative to the inorganic NPK source. In addition, manure is a nutrient source that releases nutrients more slowly than inorganic commercial NPK sources. In a study with rice by Rahimabadi et al. [170], a decrease in 1000-grain weight was found with the application of 15 and 30 Mg of cow manure in comparison to the control. However, there was a significant grain yield increase of more than 800 kg ha<sup>-1</sup> with 30 Mg of manure ha<sup>-1</sup> in both years of the study. The effect of manure on yield is not only dependent on the manure characteristics, but also on climatic factors. Nikiema et al. [171] found that wheat yield was not affected by liquid hog manure in below average precipitation years. This can be attributed to a low yield potential under low precipitation, affecting the response to nutrients negatively. However, when precipitation was above average, there was a 20%, 30%, and 50% increase in grain yield with 64, 128, and 192 kg of manure N ha<sup>-1</sup>, respectively [171]. The study also showed an increase in straw yield with increasing manure rate, with the highest yield of 5.1 kg ha<sup>-1</sup> with the application of 192 kg of N ha<sup>-1</sup> in manure. Additional yield components of wheat were investigated by Jan et al. [172], who found that 1.5 Mg ha<sup>-1</sup> of poultry manure increased spike length, 1000-grain weight, and grain yield. None of these yield components significantly increased any further with the application of 2 Mg ha<sup>-1</sup>. Interesting about

this experiment is that the soil of the experimental site was alkaline and low in available N ( $0.04 \text{ g kg}^{-1}$ ) and P ( $4 \text{ mg kg}^{-1}$ ). The low levels of N and P might explain the response of the wheat to the manure. Koutroubas et al. [173] reported that there was no significant increase in dry matter wheat yield between the control (no manure, no synthetic fertilizer) and  $16 \text{ Mg ha}^{-1}$  farmyard manure treatment. However, there was a significant increase of more than  $2 \text{ Mg}$  dry matter with  $32 \text{ Mg ha}^{-1}$  manure application. The same trend was found with grain yield, however, there was no significant difference in grain weight between treatments. Interestingly, this study found that the high rate of manure gave similar yields as the inorganic N fertilizer treatment of  $120 \text{ kg N ha}^{-1}$ , implying that the yield response depended on the availability of N. The N in synthetic fertilizer is more directly available in comparison to N in manure because of the slow release of organic N in manure and ammonia loss when manure is surface applied [174]. The results from literature show that the effect of manure on yield and yield components is a function of various external factors including soil and climatic factors.

Table 6. Grain yield in maize, rice, wheat, and sorghum as affected by manure application.

Study Site	Nutrient	Crop	Grain Yield(s)	Source
	Source	Quantity $\text{Mg ha}^{-1}$	$\text{Mg ha}^{-1}$	
United States	Cattle	0	3.80	[175]
		22.5	4.40	
		45	4.30	
		90	4.20	
		180	3.60	
	Cattle	0	2.50	[175]
		22.5	2.30	
		45	2.30	
		90	2.20	
		180	2.20	
Greece	Cattle	0	3.28	[173]
		16	3.49	
		32	4.50	
Nigeria	Poultry	0	1.33, 0.81 †	[176]
		5	2.76, 1.98	
		10	2.87, 1.66	
		15	3.63, 0.83	
		20	2.82, 2.82	
Nigeria	Poultry	0	1.90	[26]
		5	3.72	
		10	2.95	
India	Cattle	0	2.23	[177]
		40 §	3.47	
Germany	Cattle	0	5.15, 5.27 †	[178]
		80 §	5.48, 5.84	
		160 §	5.53, 6.19	
		240 §	--; 6.34	
United States	Cattle	0	6.9, 6.5, 6.3	[174]
		56 §	7.2, 7.3, 6.9	
		112 §	7.3, 7.5, 5.9	
		168 §	6.6, 7.8, 7.0	

† numbers separated by a comma indicate the numbers in different years or seasons at a single location; § Presented in  $\text{kg N ha}^{-1}$  of cattle manure.

## 17. Summary

Soil health is a broad term that speaks to the capacity of the soil to function as an ecosystem that supports the plant, animal, and human life. This review shows that manure contributes to creating this ecosystem in supplying nutrients and improving various soil properties (Table 7). The extent to which it does, however, can be variable and depends on various factors including chemical and physical properties of the manure itself and external factors including climatic factors and soil characteristics (Table 7). While, the benefits of manure on various soil properties are clear, conclusions about the effect of manure on some soil properties must be approached cautiously. The many benefits to soil must also

translate to improved plant and or animal productivity all while reducing the risks to the environment. Improved soil fertility, water movement and retention, and soil temperature regulation do facilitate better growth and higher productivity of crops. The high variability in manure characteristics and thus the unpredictability of the response to the environment pose a challenge to sustainable management of manure. The application of nutrients in excess of what the plant needs can end up in the environment through several pathways of loss such as erosion, runoff, leaching, and volatilization which may lead to deterioration of air, soil, and water quality. Moreover, the large amounts of manure that must be applied to get equal quantities of nutrients as synthetic fertilizers, make its application to land unappealing from a labor and cost perspective. Hauling large quantities of manure lead to increased expenses for transport. Moreover, the surge in availability of fertilizer products with a high percentage of needed nutrients make them cheaper per unit nutrient relative to manure [179]. Because of the potential risk to the environment, the U.S and many other countries have developed restrictions and regulations for storage and spreading of manure. The establishment and implementation of regulation imply that society recognizes the importance of this resource and its benefit to agricultural production and sustainability of the environment. It is evident that the benefits of manure application to overall soil quality are numerous, as shown in the 130 studies evaluated for this paper, and that its application to land is a viable option to improve and perhaps restore the health of degraded land. Although the papers reviewed for this work address many aspects of soil health and yield in relationship to manure, there remain aspects of manure in relationship to soil and plant that may be explored in future research. One of which is the nutrient use efficiency from manure; finding ways to improve the uptake of nutrients from manure may reduce the loss of nutrients from land and the subsequent pollution of the environment. In addition, although various works have looked at long-term application of manure and its effect on soil health indicators [18,36,39,47], there remains a need to better understand manure decomposition and its effect on soil health as a function of time. Finally, if manure is to become an attractive amendment to farmers for soil improvement, the economic sustainability of manure-based cropping systems and opportunities to improve their profitability must be explored.

Table 7. Summary of key findings from this review study.

Variable	Key Findings	References
Soil chemical properties	Applied animal manure resulted in a higher amount of SOM when compared to inorganic fertilizer. This led to the building up of SOM in the soil profile	[42]
	While not consistent, applied livestock manure increased CEC by as much as 10 cmol <sub>c</sub> kg <sup>-1</sup> relative to the control treatment. This was due to the presence of organic matter present in manure	[27,69,70]
	Repeated manure application led to the build-up of P in the soil with the potential to cause eutrophication	[39,42]
	Generally, manure application tended to lead to an increase in soil pH due to the presence of CaCO <sub>3</sub> and HCO <sub>3</sub> <sup>-</sup> . Properties of manure type and soil conditions dictate soil acidity	[23,58–60]
	Leaching of NO <sub>3</sub> <sup>-</sup> was least for manure applied in spring and highest for fall-applied manure	[32,33]
Soil physical properties	Manure was vital for lowering soil bulk density, thus, increasing soil pores to support growth of crop roots	[35,37]
	Increased infiltration rate and water holding capacity of the soil due to increased soil organic matter aggregation of soil particles	[103,107–110,112]
	Depending on the time, rate, and properties of manure applied, soil temperature could increase or decrease	[37,129–131]



Table 7. Cont.

Variable	Key Findings	References
Soil biological properties	Applied animal manure improved fungal and bacterial diversity in the soil. This is important for mineralization and root extension to extract nutrients from lower soil layers	[146–148,155,156]
	Increased microbial population improved SOC. Additionally, soil microbial C was associated with SOC	[12,154]
	Increased microbial activities such as mineralization of soil organic matter, colonization of plant root, soil aggregation e.g., via fungal hyphae and microbial C	[162–164]
Yield and Yield Components	Manure application improved grain yield over no fertilization of crops due to supply of macronutrients. Application based on N leads to P overapplication	[26,173,175,176]
	Both manure characteristics and climatic conditions dictate whether crops will respond to applied manure	[171]
	Some studies found 1000-grain weight to reduce and no yield difference between manure treated and control plots due to the slow-release nature of manure	[169,170]

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*Article*

## Implementation of BMP Strategies for Adaptation to Climate Change and Land Use Change in a Pasture-Dominated Watershed

Li-Chi Chiang <sup>1</sup>, Indrajeet Chaubey <sup>2</sup>, Nien-Ming Hong <sup>3</sup>, Yu-Pin Lin <sup>1,\*</sup> and Tao Huang <sup>1</sup>

<sup>1</sup> Department of Bioenvironmental Systems Engineering, National Taiwan University, 1, Section 4, Roosevelt Road, Da-an District, Taipei City 106, Taiwan; E-Mails: lchiang@ntu.edu.tw (L.-C.C.); jay7753@hotmail.com (T.H.)

<sup>2</sup> Department of Agricultural and Biological Engineering, Purdue University, 225 South University Street West Lafayette, IN 47907, USA; E-Mail: ichaubey@purdue.edu

<sup>3</sup> Environment and Energy Management Center, Overseas Chinese University, No. 100, Chiao Kwang Road, Taichung 407, Taiwan; E-Mail: hong@ocu.edu.tw

\* Author to whom correspondence should be addressed; E-Mail: yplin@ntu.edu.tw;  
Tel./Fax: +886-2-336-634-67.

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**Abstract:** Implementing a suite of best management practices (BMPs) can reduce non-point source (NPS) pollutants from various land use activities. Watershed models are generally used to evaluate the effectiveness of BMP performance in improving water quality as the basis for watershed management recommendations. This study evaluates 171 management practice combinations that incorporate nutrient management, vegetated filter strips (VFS) and grazing management for their performances in improving water quality in a pasture-dominated watershed with dynamic land use changes during 1992–2007 by using the Soil and Water Assessment Tool (SWAT). These selected BMPs were further examined with future climate conditions (2010–2069) downscaled from three general circulation models (GCMs) for understanding how climate change may impact BMP performance. Simulation results indicate that total nitrogen (TN) and total phosphorus (TP) losses increase with increasing litter application rates. Alum-treated litter applications resulted in greater TN losses, and fewer TP losses than the losses from untreated poultry litter applications. For the same litter application rates, sediment and TP losses are greater

for summer applications than fall and spring applications, while TN losses are greater for fall applications. Overgrazing management resulted in the greatest sediment and phosphorus losses, and VFS is the most influential management practice in reducing pollutant losses. Simulations also indicate that climate change impacts TSS losses the most, resulting in a larger magnitude of TSS losses. However, the performance of selected BMPs in reducing TN and TP losses was more stable in future climate change conditions than in the BMP performance in the historical climate condition. We recommend that selection of BMPs to reduce TSS losses should be a priority concern when multiple uses of BMPs that benefit nutrient reductions are considered in a watershed. Therefore, the BMP combination of spring litter application, optimum grazing management and filter strip with a VFS ratio of 42 could be a promising alternative for use in mitigating future climate change.

**Keywords:** best management practice (BMP); climate change; land use change; soil and water assessment tool (SWAT); nonpoint source pollution

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## 1. Introduction

Best management practices (BMPs) are often used to control the losses of non-point source (NPS) pollutants to receiving water bodies. Selection of BMPs is specific to topographic, soil, land use, and climate conditions. For example, NRCS recommended using phosphorus index (PI) rating, soil phosphorus threshold values, or soil test to establish acceptable phosphorus application rates [1]. Different approaches to mitigate animal waste problems were adopted in the Rural Clean Water Program (RCWP) projects conducted in the American states of Utah and Florida due to their different climatic characteristics [2]. Multiple BMPs are usually combined together in a watershed, such as tillage and nutrient management practices [3] or grazing management and vegetative buffers [4] to effectively control pollutants from various sources. When numerous BMP options are available, whether various combinations of BMPs work synergistically or cancel the effect of each other when implemented together in a watershed must be evaluated [5–7].

The Conservation Effects Assessment Project (CEAP) was initiated by the USDA Natural Resources Conservation Service (NRCS), Agricultural Research Service (ARS), and Cooperative State Research, Education and Extension Service (CSREES) (now National Institute of Food and Agriculture or NIFA) to evaluate the effects of conservation practices at the watershed scale and to estimate the impacts of conservation practices at national and regional levels. One of the efforts of CEAP is to measure long-term watershed-specific effects of conservation practices on environmental quality. This task is performed by examining changes in water quality for a specific period when a watershed has undergone certain conservation management practices. For example, 70% and 41% of the reductions in suspended sediment concentration and total phosphorus, respectively, were found as a result of conservation practices in the Beasley Lake watershed, Mississippi, from 1995 to 2005 [8]. Increased levels of residue cover were found to be negatively correlated with nutrient concentrations and loads in the St. Joseph River watershed in Indiana, where multiple tillage management was implemented from 2006–2007 [9].

In addition to field investigation of the impacts of conservation practices, watershed models are a highly efficient means of evaluating how various combinations of BMPs can improve water quality and reduce NPS losses. These models are used to make watershed response predictions in two modes based on the time scale of interest: futurecast and hindcast. In futurecast, a watershed model is used to evaluate how various BMPs likely improve water quality. For example, Yuan [10] identified the critical areas where conservation practices must be implemented in the Mississippi Delta Beasley watershed by using the annualized agricultural non-point source (AnnAGNPS) model. According to their results, converting all crop lands to no-till soybeans or cotton reduces sediment losses by 64–77% over current conditions. By using the soil and water assessment tool (SWAT), Chaubey [5] evaluated the effectiveness of 171 BMP scenarios in a CEAP watershed from 2004–2028, as represented by 250 projected weather variations. Hindcast studies adopt a watershed model to retrospectively evaluate how much water quality was impacted by current conservation practices or how much water quality would have improved if certain suites of BMPs had been previously implemented in a watershed. For example, from 2003–2006, conservation practices reduced sediment, total nitrogen and phosphorus losses by 69%, 46% and 49%, respectively in the Upper Mississippi River Basin [1]. Locke [8] suggested that no-tillage practices could reduce sediment loadings to a range of 15%–69% of the existing condition in the Mississippi Delta region, based on AnnAGNPS model simulations. By using the soil and water assessment tool (SWAT), Bracmort [11] quantified the long-term impacts of various structural BMPs on sediment and phosphorus losses over a 25-year period (1975–2000). That study also estimated that current BMPs reduced sediment and phosphorus yield by 7–10% and 7–17%, respectively.

Designing a futurecast model often involves making climate change scenarios or land use change scenarios, which could be the main source of uncertainty in the evaluation of conservation practices [12–14]. However, hindcast modeling, which utilizes climate data and historical land use data, likely has less uncertainty and can be used to evaluate the effectiveness of current conservation practices and how water quality is improved even if another suite of BMPs has been implemented in the watershed. Additionally, the hindcasted results could be used as a baseline to evaluate how simulated future conditions impact watershed responses [15]. Therefore, this study evaluates the effectiveness of various combinations of management practices in improving water quality for the periods of 1992–2007 and 2010–2069 in the Lincoln Lake watershed, Arkansas. Additionally, the amount of pollutants that would have been reduced if the most effective management practices were implemented in the watershed is quantified. Moreover, exactly how climate change impacts water quality improvement at different spatial scales is quantified. By using the SWAT model, 171 pasture management practice scenarios are evaluated, including 19 nutrient management options, three grazing management types, and three vegetated filter strips (VFS). This study was undertaken from 1992–2007 with the implementation of several BMPs in the watershed since 1992. We hypothesized that future climate change impacts the BMP performance in different ways to improve water quality.



## 2. Materials and Methods

### 2.1. Study Area

This study was conducted in the Lincoln Lake watershed, a 32 km<sup>2</sup> agricultural watershed within the Illinois River basin located in Northwest Arkansas and Eastern Oklahoma. Moores Creek and Beatty Branch are the two major tributaries in the watershed, representing 21 and 11 km<sup>2</sup> of the watershed area, respectively. This watershed is one of the 13 watersheds in the Conservation Effectiveness Assessment Project (CEAP) funded by the USDA-CSREES. The Lincoln Lake watershed was a pasture dominated watershed where pasture lands constituted more than 48% of the entire watershed in 1992. However, due to rapid urbanization in the past 15 years, pasture lands have decreased with a concurrent increase in urban lands. Table 1 shows the land use distribution in the Lincoln Lake watershed from 1992 to 2004. In 2004, pasture, forest, urban residential and urban commercial represented 36%, 49%, 12% and 2% of the watershed area, respectively (Figure 1). There are numerous poultry, beef, and dairy cattle production facilities in the pasture fields of the watershed. High levels of fertilizer and manure usages on perennial forage crop production in the watershed have been shown to increase surface and ground water pollution due to inputs of sediment, nutrients and pathogens [16]. Since 1994, areas that had BMPs implemented in the watershed have increased from 1% to 34% of the entire watershed area, representing 53% of total pasture areas in the watershed in 2005 (Figure 2). BMPs were first implemented in the northeast part of the Beatty Branch and Upper Moores Creek subwatersheds in 1994. The western portion of the Beatty Branch and northeastern portion of the Lower Moores Creek subwatershed had BMPs implemented later in 1999. In 2005, most of the pasture lands had at least one BMP implemented, except the southwestern part of the Moores Creek subwatershed. Recommendations for BMP implementation have changed over the years from poultry litter application based on meeting plant nitrogen demand in the early 1990s to phosphorous based application in 2000. Currently, farmers are encouraged to apply alum-treated poultry litter based on the Arkansas Phosphorus Index to reduce soluble phosphorus concentration in poultry litter [17,18].

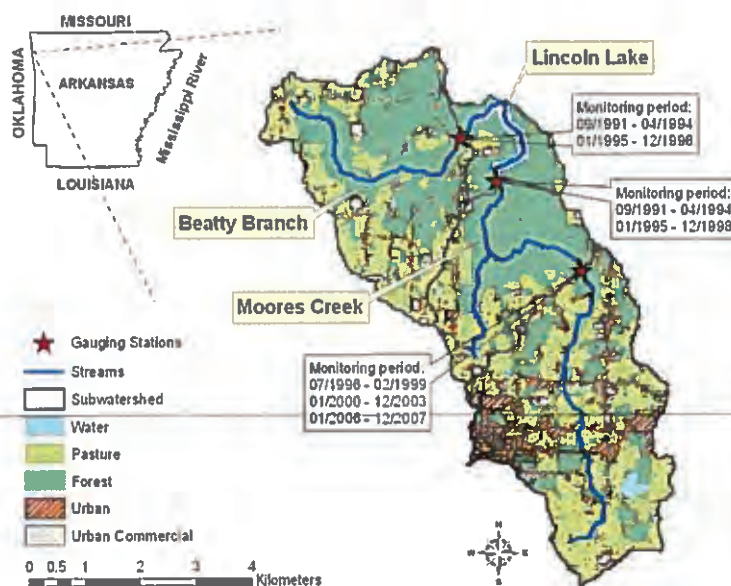
**Table 1.** Historical land use distribution in the Lincoln Lake watershed from 1992 to 2004.  
(Note: number in parenthesis denotes the percentage of the watershed).

Land Use	1992	1994	1996	1999	2001	2004
Forest	1,493 (46.4)	1,619 (50.3)	1,574 (48.9)	1,628 (50.6)	1,619 (50.3)	1,567 (48.7)
Pasture	1,532 (47.6)	1,377 (42.8)	1,322 (41.1)	1,229 (38.2)	1,164 (36.2)	1,151 (35.8)
Urban	107 (3.3)	138 (4.3)	225 (7.0)	267 (8.3)	339 (10.6)	381 (11.8)
Urban commercial	27 (0.9)	30 (0.9)	36 (1.1)	39 (1.2)	41 (1.3)	50 (1.5)
Other	58 (1.8)	53 (1.7)	61 (1.9)	55 (1.7)	54 (1.7)	70 (2.2)
Total	3,217	3,217	3,217	3,217	3,217	3,217

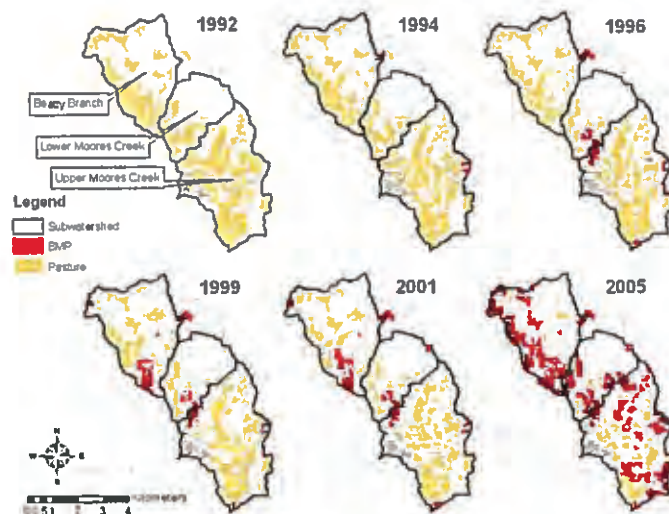
Three monitoring sites were located at the Beatty Branch, Lower Moores Creek and Upper Moores Creek with different monitoring periods depending on the monitoring projects funded in the watershed (Figure 1). Nutrient and sediment transport were first monitored from September 1991 to April 1994 at Beatty Branch (BB) and Lower Moores Creek (LMC). Vendrell [19] concluded that the BMPs were

able to retard nitrogen transport as indicated with a decrease in mean concentrations of ammonia nitrogen ( $\text{NH}_4\text{-N}$ ) and Total Kjeldahl Nitrogen (TKN) from January 1995 through December 1998 at the Lower Moores Creek and Beatty Branch sites, and from July 1996 through February 1999 at the Upper Moores Creek site, respectively. Nelson [20] compared data from 2006 to 2007 with the data from 2000 to 2003, and the results showed that TP concentration dropped nearly 50% (0.19 mg/L in 2000 and 0.1 mg/L in 2007) and nitrate-nitrogen declined by 66% (3.57 mg/L in 2000 and 1.21 mg/L in 2007) indicating that implemented BMPs resulted in reduced nutrient loads in the watershed.

**Figure 1.** Location of Beatty Branch, Moores Creek, gauging stations with monitoring periods and 2004 land use distribution in the Lincoln Lake watershed.



**Figure 2.** Location of BMPs on pasture lands in the Lincoln Lake watershed from 1992 to 2005.



## 2.2. Model Description and Input Data Preparation

The Soil and Water Assessment Tool (SWAT) model was used to estimate and hindcast the effectiveness of various management practice combinations on water quality considering the dynamic land use and management conditions in the watershed. The model can predict long-term impacts of land use and management on water, sediment and agricultural chemical yields at different scales in a mixed land use watershed [21]. The SWAT model has been widely used to quantify the linkage between BMPs and water quality at the watershed-scale in the United States [22]. The major GIS input files for the SWAT model were the digital elevation model (DEM) at 30 m resolution [23], land use and land cover [24] and SSURGO soil data. The land use maps for the years 1992, 1994, 1996, 1999, 2001 and 2004 were developed using moderate spatial resolution (28.5 m × 28.5 m) Landsat Thematic Mapper (TM) satellite images [25]. The watershed was delineated into 72 subbasins based on the DEM, specification of streams and inlets/outlets. Then the sub-basins were portioned into homogeneous units (hydrologic response units, HRUs) by setting 0% threshold percentages of land use and soil type for accurately capturing the land use change that occurred between 1992 and 2004. Weather data (daily precipitation, minimum and maximum temperature) were obtained from Fayetteville Weather Station located approximately 25 km from the watershed. Other weather variables needed by the model (solar radiation, wind speed and relative humidity) were estimated using the weather generator built into the SWAT model.

The pasture management information was collected by Washington County extension personnel and used to calculate the area-weighted average of fertilizer and manure rates for representing the existing land application and grazing management at each HRU [26]. The calculated fertilizer and manure rates, as well as grazing periods were built into the management files for pasture HRUs as SWAT input files. There were seven types of manure and fertilizers applied in the Lincoln Lake watershed. The inorganic fertilizers included urea, anhydrous ammonia, and triple 17 (17% of N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O). Organic manure included beef-fresh manure, hen/pullet manure, broiler-fresh manure, and alum-treated broiler manure. The SWAT model has the ability to define specific types of manure and fertilizers by providing detailed fertilizer and manure components, such as fractions of mineral N (or P), organic N (or P), and a ratio of ammonium to mineral N in the SWAT fertilizer database. It should be noted that the nutrient content of broiler-fresh manure and alum-treated broiler manure were based on poultry houses located in the northwest Arkansas [27,28]. The pasture management information including amount of litter and fertilizer application, timing of manure and fertilizer application, and grazing intensity and dates were obtained from a detailed review of historical nutrient management plans and interviews with 63 out of 75 farmers located in the watershed [26]. The timing and amount of litter and fertilizer application varied in this watershed during 1992–2004. The average litter application and approximate dates of application were 2,500 kg/ha applied each time on 30 April and 31 August. The daily dry weight of forage intake by grazing animals was 10.14 kg/ha/day and the dry mass of the manure excreted ranged from 0.01–14.2 kg/ha/day. The number of days animals grazed in the watershed ranged from 11–365 days/year. Detailed information of management practices and schedules for SWAT management files can be found in Chaubey [5].

In order to incorporate the dynamic land use change, the SWAT 2009 model which incorporates HRU fraction changes was used. More details about developing HRU fraction files for individual years

and how the SWAT model reads the different HRU fraction files can be found in Chiang [27]. One of the major changes in the SWAT 2009 model is to simulate vegetated filter strips (VFS) by using the VFS ratio of pollutant sourcing area to the VFS area and including the impact of concentrated flow. In the 2005 executable version of SWAT, the model simulates the performance of VFS using the VFS width alone. Several factors may influence the removal rate of chemicals through the buffers, such as forms of chemicals (soil-bound or soluble), length/width of buffer strips, vegetation types, hydrologic conditions and soil types [29–31]. Many studies have focused on simulating the sediment trapping efficiency of filter strips at the field scale, where runoff was distributed fairly uniformly over the buffer area [32,33]. However, numerous studies indicate that non-uniform flow is more common than uniform flow passing through the buffer area [34–37]. When a buffer is designed, it should be based on a ratio of upslope contributing area to effective buffer area rather than on buffer dimensions (width, length, shape, total area) alone [38,39]. Therefore, the VFS ratio is critical, especially when high loads or concentrated flow conditions exist in the VFS areas [31]. In SWAT 2009, VFS is separated into two sections during the simulation. Section one is 90% of the VFS that receives the least flow, and section two is the other 10% of the VFS that receives 25–75% of the flow [40]. Runoff and sediment loadings before passing through the VFS are calculated using the ratio of the drainage area to VFS area ( $DAFS_{ratio}$ ) for each VFS section and HRU runoff and sediment yield prediction. Sequentially, the reduction of runoff, sediment and nutrients are calculated as follows [40]:

$$R_R = 75.8 - 10.8 \ln(R_L) + 25.9 \ln(K_{SAT}) \quad (1)$$

where  $R_R$  is the runoff reduction (%);  $R_L$  is the runoff loading (mm); and  $K_{SAT}$  is the saturated hydraulic conductivity (mm/h).

$$S_R = 79 - 1.04 S_L + 0.213 R_R \quad (2)$$

where  $S_R$  is the sediment reduction (%);  $S_L$  is the sediment loading ( $kg/m^2$ ); and  $R_R$  is the runoff reduction (%).

$$TN_R = 0.036 S_R^{1.69} \quad (3)$$

where  $TN_R$  is the total nitrogen reduction (%); and  $S_R$  is the sediment reduction (%).

$$TP_R = 0.9 S_R \quad (4)$$

where  $TP_R$  is the total phosphorus reduction (%); and  $S_R$  is the sediment reduction (%).

The SWAT outputs include flow and water quality information at different temporal (daily, monthly and annual) and spatial (HRU, subbasin, watershed) scales. In this study, monthly flow, sediment, nitrogen and phosphorus loads at the gauging station were of interest for model calibration and validation. The annual pollutant loads at a subbasin were calculated by multiplying the annual area-averaged pollutant loads from a HRU by the HRU area, and then summing the annual loads at each HRU in the subbasin. These processed outputs were used to quantify the amount of pollutant losses if a certain suite of BMPs was implemented in the watershed.



### 2.3. SWAT Model Calibration and Validation

Sensitivity analysis is usually performed to identify which parameters in a model most influence outputs of interest. Based on the sensitivity analysis results and the identified calibration parameters in several SWAT publications, 13 parameters were modified for calibrating flow, sediment, nitrogen and phosphorus in this study [11,41]. Model calibration and validation were performed for monthly stream flow, TSS, TN and TP using the measured flow and water quality data collected at the Upper Moores Creek for the period 01/1996–2/1999, 01/2000–12/2003 and 01/2006–12/2007. Measured stream flow data were available for 8 years, while water quality data (TSS, TN and TP) were only available for seven years, which was the same monitoring period as flow except the year of 1996. In order to make the model comprehensively capture the watershed responses, we selected 01/2001–12/2003 and 01/2006–12/2007 as the model calibration period due to major land use changes that occurred during this period. Subsequently, we selected 01/1996–2/1999 and 1/2000–12/2000 as the model validation period for flow and 01/1997–2/1999 and 1/2000–12/2000 for TSS, TN and TP.

Flow was calibrated first because it can influence other outputs [41] and it has less measurement uncertainty [42]. Flow calibration was followed by sediment calibration because organic nitrogen and phosphorus are usually attached on sediment and transported in runoff [43,44]. Two quantitative statistics used for model evaluation were Nash-Sutcliffe efficiency (NSE) [45] and coefficient of determination ( $R^2$ ). The Nash-Sutcliffe efficiency (NSE) is a normalized statistic indicating how well the observed and predicted data fit the 1:1 line [45]. Predicted results with an NSE value greater than 0.5 is regarded as satisfactory [46]. The coefficient of determination ( $R^2$ ) describes the portion of the variance in the measured data that are explained by the model. The greater  $R^2$  values indicate a less error variance and a model with  $R^2$  value greater than 0.5 is usually considered acceptable [47,48].

The process of calibration was repeated by adjusting the parameters and computing NSE and  $R^2$  between observed and predicted data to ensure that in optimizing one variable, other variables were not substantially influenced [41]. To test if the parameters were appropriately selected for model calibration, model validation was performed for evaluating the accuracy of the model by comparing simulation results to a different set of observation data from the calibration dataset.

### 2.4. Management Practice Scenarios

The watershed management practice scenarios considered in this study were grouped into three categories: grazing management, vegetated filter strips (VFS), and nutrient management. These scenarios were based on detailed interactions with the watershed stakeholders and history of past BMPs implemented in the watershed [26].

**Grazing management:** Three grazing intensities were considered: (1) no grazing; (2) optimum grazing; and (3) overgrazing. Based on detailed discussion with the county extension experts, the minimum plant biomass for grazing to occur was set at 2,700 and 1,009 kg/ha, respectively, for optimum and overgrazing (Ron Morrow, personal communication). The overgrazing application started on 30 September and lasted for 213 days until 30 April of the next year. Typically, optimum grazing comprises rotating grazing animals through various HRUs such that a minimum biomass is maintained in the field. Based on information on typical optimum grazing management, it was

assumed that within 30 days the cattle should graze through the whole watershed and would stay for approximately 4–6 days in each pasture HRU [49]. This approach was similar to grazing operations reported in other watersheds located near the study area [41].

**Vegetated filter strips (VFS):** Vegetated filter strips (VFS) have been proven to be an effective management practice for trapping sediment and nutrients in field runoff [50–52]. The Natural Resources Conservation Service (NRCS) has developed a method to design and estimate sediment removal from VFS using the Revised Universal Soil Loss Equation, Version 2 (RUSLE2) [53] in which VFS are designed to have a minimum 10-year life time and the VFS need to be re-established once the sediment accumulation reaches 6 inches [54]. NRCS developed an equation to calculate the number of years to reach 6 inches at the annual sediment accumulation rate. The annual sediment accumulation rate is calculated as follows:

$$\text{Rate}_{\text{sed}} = \text{Sed} \times 21.74(\text{ft}^3/\text{ton}) \times \text{Trap}_{\text{sed}} \times \text{VFS}_{\text{ratio}} \times 43,560(\text{ft}^2/\text{acre}) \times 12(\text{in}/\text{ft}) \quad (5)$$

where  $\text{Rate}_{\text{sed}}$  is the annual sediment accumulation rate (in/year); Sed is sediment delivery to VFS (tons/acre/year);  $\text{Trap}_{\text{sed}}$  is the trapping efficiency; and  $\text{VFS}_{\text{ratio}}$  is the ratio of contributing field area to VFS area.

In this study, the life time of the VFS was assumed to be 25 years, and different levels of trapping efficiency were set equal to 29%, 56% and 100% based on various studies in the Southeastern U.S. region [7,37,55]. The maximum annual sediment loads (2,333 kg/ha/year), which were estimated with 250 weather realizations during a 25-year simulation period in previous study [5], were selected to design VFS ratios with three levels of trapping efficiency under the worst condition of sediment delivery. The VFS ratios were calculated inversely using Equation (5). Thus, VFS ratios were designed to be 146, 76 and 42, respectively, with the trapping efficiency of 29%, 56% and 100% to maintain a VFS functional period of 25 years. In other words, when the VFS ratio is 42 at any trapping efficiency, it will take at least 25 years to accumulate 150 mm in the VFS. Similarly, when the VFS ratio is 76, the VFS can function for 14–48 years with the trapping efficiency 100%–29%. However, if the VFS ratio is 146 with greater than 82% trapping efficiency, the life time of VFS will be shorter than 9 years. Therefore, we selected VFS ratios of 42 and 76 as two different levels of VFS that could be implemented in the watershed.

**Nutrient management:** Nutrient management scenarios evaluated in this study included various poultry litter application rates, litter characteristics, and application timing. DeLaune [18] suggested that the litter application in pasture areas should not exceed 4.94 t/ha for warm season grasses, and 7.41 t/ha for cool season grasses in nutrient surplus watersheds in Northwest Arkansas. Therefore, the litter application rates evaluated were 2.47, 3.71 and 4.94 t/ha in spring (applied on 30 April) and summer (31 August) to support growth of warm season grasses, and 4.94, 6.18 and 7.41 t/ha in fall (15 October) to support growth of cool season grasses. For all application rates and timings evaluated in this study, two types of poultry litter were selected—normal poultry litter and alum-amended litter. Many studies have shown that the alum-amended litter was able to reduce P losses in surface runoff and leaching [51,56,57]. Additionally, alum in poultry litter was shown to increase yields due to greater N mineralization and less  $\text{NH}_3$  emissions [57,58]. The total number of nutrient management scenarios evaluated was 18 (3 nutrient application rates  $\times$  3 application timings  $\times$  2 litter types).

Management practice scenarios which consist of no litter application with any grazing management and VFS implementation were also added for further comparison.

The combination of above management practices resulted in 171 different management practice scenarios. The pasture management practices that existed in the watershed during 1992–2007 were regarded as baseline (scenario 172) and were used to compare the effectiveness of selected management practice combinations in reducing NPS pollutants of concern from the watershed.

## 2.5. Climate Change Scenarios

The future 100-year climate condition with no climate change was first generated using the historical climate data from 1970 to 1999. This no climate change (NCC) condition retains the same statistical characteristics as the historical climate data. Three GCMs (general circulation models) simulations were used to generate short-term (2010–2039) and mid-term (2040–2069) climate change conditions. Those GCMs are CCSM (National Center for Atmospheric Research, NCAR, Community Climate System Model, version 3.0), CGCM2 (Meteorological Research Institute, Japan Meteorological Agency, MRI-CGCM2.3.2), and GFDL21 (Geophysical Fluid Dynamics Laboratory, NOAA, CM2.1). All the data for the GCMs were obtained from the Data Distribution Centre of the Intergovernmental Panel on Climate Change (IPCC). Since the spatial resolutions of GCMs are too coarse to represent local climate characteristics in the watershed, the technique of simple downscaling between the baseline and the climate scenario of the nearest GCM grid was applied directly.

The future change in temperature in the study area is assumed to be the same as the difference between temperatures simulated using GCMs for the future and current conditions at the weather station [59,60]:

$$\mu'_{mT} = \mu_{mT} + (\mu_{mT, \text{future}} - \mu_{mT, \text{current}}) \quad (6)$$

where  $\mu_{mT}$  and  $\mu'_{mT}$  are the current and future mean monthly temperature (°C) respectively; and  $\mu_{mT, \text{current}}$  and  $\mu_{mT, \text{future}}$  are, respectively, the simulated mean monthly temperature (°C) under the current and future scenarios (the annual average for 2010–2039) climate conditions respectively.

The future change in precipitation in this study area is assumed to be the ratio of the precipitation for the future condition to that for the current condition [60]:

$$\mu'_{mP} = \mu_{mP} \times (\mu_{mP, \text{future}} / \mu_{mP, \text{current}}) \quad (7)$$

Where  $\mu_{mP}$  and  $\mu'_{mP}$  are the current and future mean monthly precipitation (cm), respectively; and  $\mu_{mP, \text{current}}$  and  $\mu_{mP, \text{future}}$  are the simulated mean monthly precipitation (cm) under the current and future climate conditions, respectively.

We utilized Tung and Haith's [61] weather generation model to generate daily temperature and precipitation data for the target climate scenarios. In order to produce as many combinations of weather variability as possible, a total of 100 years of daily weather data were generated for the baseline and climate scenarios. Table 2 lists the annual average temperature and precipitation for each climate change scenario.

## 2.6. Selection of the Best and Worst Pasture Management Practice Combinations

The management practices with the maximum constituent losses is regarded as the worst management practice combination for water quality improvement, while the management practices having the minimum losses is regarded as the best management practice combination. The best and worst scenarios are not the same for all pollutants. For example, litter application can increase the biomass production, infiltration and reduce sediment losses, but meanwhile an increase in nutrient inputs on pasture may exceed nutrient demand of the forage and can lead to greater nutrient losses from the watershed.

**Table 2.** The annual average temperature and precipitation. (Note: Historical climate denotes the observed weather data from 1990–2007; NCC denotes no climate change condition).

Scenarios	Max. Temperature	Min. Temperature	Precipitation (mm)
Historical climate	20.7	9.3	1,245.5
NCC	20.2	8.5	1,105.4
CCSM_S	22.4	10.5	1,063.5
CCSM_M	23.6	11.6	1,170.3
CGCM_S	21.4	9.6	1,069.5
CGCM_M	22.2	10.3	1,114.4
GFDL_S	21.4	9.6	1,080.2
GFDL_M	22.8	10.9	995.0

## 3. Results and Discussion

### 3.1. SWAT Model Performance

Table 3 lists the ranges, default values and calibrated values of the SWAT parameters. The ranges of the SWAT parameters were obtained from the literature [11,62]. The model was initially run using the default SWAT parameters, and the monthly predictions from each step of the model calibration were compared with the monthly measured data at the Upper Moores Creek. The default CN values for each land use were decreased by 10%, indicating that the Lincoln Lake watershed has better soil drainage than the general conditions in the SWAT database.

The ESCO value was decreased from 0.95 to 0.26 to allow for greater evaporation from lower soil layers. Because of a high base flow, the GWQMN value was increased to 3,000 mm to increase deep percolation losses, a condition typical to karst topography in the watershed. NPERCO and PPERCO values were increased because of a low mineral nitrogen loading and low soluble phosphorus loading, respectively. The PHOSKD value was not linearly related to TP, and PHOSKD = 100 was the optimal value for TP calibration.



**Table 3.** List of calibration SWAT parameters for each output of interest for the Lincoln Lake watershed SWAT model.

Output	SWAT parameters (Unit)	Short Description	Range	Default	Calibrated
Flow	CN	Initial SCS runoff curve number	39–98	75.25	67.725 (–10%)
	ESCO	Soil evaporation compensation factor	0–1	0.95	0.26
	GWQMN (mm)	Threshold depth of water in shallow aquifer	0–5,000	0	3,000
TSS	SLOPE (m/m)	Average slope steepness	0–0.6	0.072	0.036
	USLE_K	USLE equation soil erodibility K factor	0.01–0.65	0.345	0.1725
	ADJ_PKR	Peak rate adjustment factor for sediment routing in the main channel	0.1–2	1	2
TN	NPERCO	Nitrate percolation coefficient	0.001–1	0.2	1
	CMN	Rate factor for mineralization of active organic nutrients	0.001–0.004	0.003	0.004
TP	PPERCO	Phosphorus percolation coefficient	10–17.5	10	17.5
	PHOSKD	Phosphorus soil partitioning coefficient	40–300	175	100

The model calibration and validation results were evaluated using Nash-Sutcliffe efficiency (NSE) and coefficient of determination ( $R^2$ ) as the model performance criteria (Table 4). For calibration, the NSE and  $R^2$  values for flow, TSS, TN and TP were equal to or greater than 0.5, which is generally viewed as a satisfactory model performance [46–48]. For validation, the performance of the model in simulating the flow and TP was satisfactory, as indicated by NSE and  $R^2$  values greater than 0.5. Except for one indication of unsatisfactory model performances (NSE = 0.25 and 0.33 for TSS and TN, respectively), the model simulation of TSS and TN was satisfactory. Our results indicated some extremely high measured TSS and TN values that the model could not simulate resulting in the NSE values for TSS and TN lower than 0.5. The NSE values increased to 0.64 and 0.53 for TSS and TN after the outliers (4 measured monthly TSS values ranging from 238–550 kg/ha and 4 measured monthly TN values ranging from 0.73–0.85 kg/ha) were removed. Concurrently, the  $R^2$  values for TSS and TN increased to 0.75 and 0.73, respectively. Overall, the model calibration and validation were satisfactory based on NSE and  $R^2$  as the model performance criteria.

**Table 4.** Results of calibration and validation of the SWAT model for monthly flow, total suspended sediment (TSS), nitrogen (TN) and phosphorus (TP).

Variable	Calibration				Validation			
	Observed	Predicted	NSE	$R^2$	Observed	Predicted	NSE	$R^2$
	Mean	Mean			Mean	Mean		
Flow (m <sup>3</sup> /s)	3.31	3.00	0.52	0.55	3.83	2.18	0.60	0.76
TSS (kg/ha)	20.34	26.11	0.58	0.73	44.15	16.09	0.25	0.67
TN (kg/ha)	0.55	0.32	0.50	0.66	0.73	0.33	0.33	0.5
TP (kg/ha)	0.09	0.10	0.60	0.72	0.14	0.09	0.73	0.89

### 3.2. Performance of Management Practices

#### 3.2.1. Under Historical Climate Condition (1992–2007)

Many studies have evaluated the hydrological impacts of land use changes by hypothetically predicting the land use changes, such as conversion of the entire watershed to agricultural lands, or systematically changing land use distribution at different percentages [12,14]. Such simulation results may fail to provide an expectation on how a watershed would respond when a complex land use change occurs. This study incorporated the historical land use changes with corresponding agricultural management, and measured weather data into the model simulation to reduce the uncertainty in the evaluation of current conservation practices. Additionally, evaluating the performance of alternative conservation practices that would have further improved water quality provides more precise information on their effectiveness for making future watershed management decisions. Tables 5, 6, and 7 summarize the effectiveness of 171 different management practice combinations in reducing annual pollutant losses from the watershed for total suspended sediment (TSS), total N (TN), and total P (TP), respectively. Notably, the values shown in these tables are the average annual values during the simulation period (1992–2007) and can be considered as the average watershed responses for these management practice scenarios. These simulation results for 171 scenarios were compared with the pollutant losses from the current management practice (baseline) scenario, which included various pasture management practices in the watershed from 1992 to 2007 [5].

The best management practice combination for mitigating TSS losses is scenario 61, which is a combination of 4.94 t/ha alum-amended litter applied in spring, no grazing and a VFS ratio of 42. The worst management practice combination is scenario 39, which is a combination of no litter application, overgrazing and no VFS. Vegetated filter strips (VFS) were the most influential management practices for reducing sediment losses. In the same field, a smaller VFS ratio indicates a larger VFS compared to a larger VFS ratio, indicating that a smaller VFS is implemented. In this study, the VFS ratios were derived using the maximum sediment loads (2,333 kg/ha/year) from the Lincoln Lake watershed under various weather conditions during a 25-year period (2004–2028). However, the maximum sediment loads (224.3 kg/ha/year for scenario 39) from the watershed over the past 16 years (1992–2007) were significantly less than the sediment loads in extreme weather conditions. Therefore, a VFS ratio of 76 could reduce sediment losses by 14.1%–23.8% compared with the baseline scenario. A VFS ratio of 42 resulted in similar sediment losses ranging from 127.1 to 141.1 kg/ha/year (Table 5) with corresponding reductions of 24.2% and 15.8%, respectively. When no VFS was implemented, overgrazing increased sediment losses from 164.7 to 224.3 kg/ha/year as the results of a loss of vegetative cover, soil compaction and reduction in infiltration. When no VFS was implemented, TSS losses generally increased with the intensity of grazing for all nutrient management scenarios. Litter application timing also affected the losses of sediment. For example, TSS losses of 197.5, 179.7, and 159.3 kg/ha/year were simulated when 4.94 t/ha alum-treated litter was applied in summer, fall and spring seasons, respectively. Spring and fall are the primary growing seasons for Bermuda grass and Fescue grass, while Bermuda was harvested twice in mid July and September. Therefore, summer application affected growth of grass to a lesser extent, and TSS losses were greater than those for

spring and fall applications. Additionally, plants may experience nutrient stress when no litter is applied, resulting in less vegetated cover and increased losses of TSS.

**Table 5.** Total suspended sediment (TSS, kg/ha) losses from the Lincoln Lake watershed under 171 management practice scenarios (NG: no grazing, OG: optimum grazing, OVG: over grazing), VFS (vegetative filter strips, no VFS, VFS ratio = 42, 76) and application timing (spring, summer and fall applications), where the number indicates the litter amount in ton/acre unit with non-alum (NA) or alum (A) amended poultry litter. Bold value and underlined value indicate the best and the worst pasture management scenarios, respectively.

Manure application (t/ha)-type	VFS ratio								
	0			42			76		
	Grazing and Pasture Management								
	NG	OG	OVG	NG	OG	OVG	NG	OG	OVG
No application	187.1	195.3	224.3	133.0	134.8	141.1	134.2	136.3	144.0
Spring									
2.47A	166.1	167.8	177.0	128.4	128.7	130.4	129.1	129.4	131.3
3.71A	162.1	163.2	169.5	127.6	127.8	128.9	128.2	128.4	129.7
4.94A	159.3	160.0	164.7	127.1	127.2	128.0	127.6	127.8	128.6
2.47NA	168.2	170.5	182.3	128.9	129.3	131.4	129.6	130.1	132.4
3.71NA	164.4	165.9	174.7	128.1	128.3	129.9	128.7	129.0	130.7
4.94NA	161.4	162.5	169.1	127.5	127.7	128.8	128.1	128.3	129.5
Summer									
2.47A	165.3	167.9	186.4	128.5	129.0	132.6	129.2	129.7	133.8
3.71A	172.2	172.9	183.8	129.9	129.9	131.7	130.8	130.8	132.8
4.94A	197.5	198.3	210.8	135.1	135.1	137.3	137.1	137.0	139.4
2.47NA	166.4	169.2	190.1	128.7	129.3	133.4	129.4	130.0	134.8
3.71NA	164.1	166.3	181.0	128.2	128.6	131.3	128.9	129.3	132.4
4.94NA	170.0	170.5	180.0	129.4	129.4	131.0	130.2	130.2	132.0
Fall									
4.94A	179.7	180.9	187.3	131.5	131.7	132.7	132.8	133.0	134.0
6.18A	184.2	185.7	193.8	132.4	132.7	134.1	133.9	134.2	135.7
7.41A	180.0	181.4	189.6	131.5	131.7	133.2	132.7	133.0	134.7
4.94NA	167.4	168.1	172.6	129.1	129.2	129.8	129.9	130.0	130.6
6.18NA	175.3	176.1	180.1	130.7	130.8	131.4	131.8	131.9	132.5
7.41NA	181.8	182.7	187.4	132.0	132.2	132.9	133.4	133.5	134.3

The best management practice combination (*i.e.*, scenario 77) for cumulative TN losses comprises no litter application, optimum grazing and a VFS ratio of 42, while the worst management practice combination (*i.e.*, scenario 16) consists of 7.41 t/ha alum-treated litter application in the fall, no grazing and no VFS. Overgrazing decreased losses of TN from the watershed for all litter application rates, application timings, and VFS ratios (Table 6). Nutrients are normally removed from pastures by

hayage or by animals through grazing. When a pasture is grazed, nutrients can be returned to pasture lands via animal urine and feces excreted. Since nitrogen is usually the limiting nutrient for pasture growth, nitrogen inputs as fertilizer or manure are needed to sustain forage production. Therefore, overgrazing reduced TN losses, possibly because the amount of N removed via forage consumed by grazing animals is greater than that of N returned to the pasture in the form of animal manure. However, overgrazing increased TN losses when no litter was applied.

**Table 6.** Total nitrogen (TN, kg/ha) losses from the Lincoln Lake watershed under 171 management practice scenarios (NG: no grazing, OG: optimum grazing, OVG: over grazing), VFS (vegetative filter strips, no VFS, VFS ratio = 42, 76) and application timing (spring, summer and fall applications), where the number indicates the litter amount in ton/acre unit with non-alum (NA) or alum (A) amended poultry litter. Bold value and underlined value indicate the best and the worst pasture management scenarios, respectively.

Manure application (t/ha)-type	VFS ratio								
	0			42			76		
	Grazing and Pasture Management								
	NG	OG	OVG	NG	OG	OVG	NG	OG	OVG
No application	3.0	3.0	3.1	2.4	2.4	2.5	2.4	2.4	2.5
Spring									
2.47A	3.3	3.3	3.2	2.5	2.5	2.5	2.6	2.6	2.5
3.71A	3.5	3.5	3.3	2.6	2.6	2.6	2.7	2.6	2.6
4.94A	3.7	3.6	3.5	2.7	2.7	2.6	2.7	2.7	2.7
2.47NA	3.2	3.2	3.1	2.5	2.5	2.5	2.6	2.5	2.5
3.71NA	3.4	3.4	3.2	2.6	2.6	2.5	2.6	2.6	2.5
4.94NA	3.5	3.5	3.4	2.6	2.6	2.6	2.7	2.7	2.6
Summer									
2.47A	3.6	3.6	3.5	2.7	2.7	2.6	2.7	2.7	2.7
3.71A	4.3	4.2	4.0	2.9	2.9	2.8	3.0	2.9	2.9
4.94A	5.1	5.0	4.9	3.2	3.2	3.1	3.3	3.3	3.2
2.47NA	3.5	3.5	3.4	2.6	2.6	2.6	2.7	2.7	2.6
3.71NA	3.8	3.8	3.7	2.8	2.7	2.7	2.8	2.8	2.7
4.94NA	4.2	4.2	4.0	2.9	2.9	2.8	3.0	2.9	2.9
Fall									
4.94A	5.3	5.3	5.1	3.3	3.3	3.2	3.4	3.4	3.3
6.18A	6.0	5.9	5.8	3.6	3.6	3.5	3.7	3.7	3.6
7.41A	6.5	6.5	6.3	3.8	3.8	3.7	3.9	3.9	3.8
4.94NA	4.5	4.4	4.3	3.0	3.0	2.9	3.1	3.1	3.0
6.18NA	4.9	4.9	4.7	3.2	3.2	3.1	3.3	3.3	3.2
7.41NA	5.4	5.4	5.2	3.4	3.4	3.3	3.5	3.5	3.4



The greatest TN losses were predicted for fall litter applications under all application rates. Additionally, vegetated filter strips decreased TN losses significantly and a smaller VFS ratio was more effective in reducing TN losses than greater VFS ratios.

Table 7 lists the TP losses from the watershed for 171 management practice scenarios evaluated in this study. Overall, TP losses were reduced by 43.4–68.1% compared with the baseline scenario. The worst case scenario (*i.e.*, scenario 57) is a combination of 3 tons/acre litter application, overgrazing management and no VFS. Meanwhile, the best management practice scenario (*i.e.*, scenario 58) is a combination of no litter application, no grazing and a VFS ratio of 42.

**Table 7.** Total phosphorus (TP, kg/ha) losses from the Lincoln Lake watershed under 171 management practice scenarios (NG: no grazing, OG: optimum grazing, OVG: over grazing), VFS (vegetative filter strips, no VFS, VFS ratio = 42, 76) and application timing (spring, summer and fall applications), where the number indicates the litter amount in ton/acre unit with non-alum (NA) or alum (A) amended poultry litter. Bold value and underlined value indicate the best and the worst pasture management scenarios, respectively.

Manure application (t/ha)-type	VFS ratio								
	0			42			76		
	Grazing and Pasture Management								
	NG	OG	OVG	NG	OG	OVG	NG	OG	OVG
No application	0.6	0.6	0.8	0.3	0.3	0.4	0.3	0.3	0.4
Spring									
2.47A	0.7	0.8	0.8	0.3	0.4	0.4	0.4	0.4	0.4
3.71A	0.8	0.8	0.9	0.4	0.4	0.4	0.4	0.4	0.4
4.94A	0.8	0.9	0.9	0.4	0.4	0.4	0.4	0.4	0.4
2.47NA	0.8	0.8	0.9	0.4	0.4	0.4	0.4	0.4	0.4
3.71NA	0.9	0.9	1.0	0.4	0.4	0.4	0.4	0.4	0.4
4.94NA	0.9	1.0	1.1	0.4	0.4	0.4	0.4	0.4	0.5
Summer									
2.47A	0.7	0.8	0.9	0.4	0.4	0.4	0.4	0.4	0.4
3.71A	0.8	0.9	1.0	0.4	0.4	0.4	0.4	0.4	0.4
4.94A	1.0	1.0	1.2	0.4	0.4	0.5	0.4	0.5	0.5
2.47NA	0.8	0.8	1.0	0.4	0.4	0.4	0.4	0.4	0.4
3.71NA	0.9	0.9	1.0	0.4	0.4	0.4	0.4	0.4	0.4
4.94NA	1.0	1.0	1.2	0.4	0.4	0.5	0.4	0.5	0.5
Fall									
4.94A	1.0	1.0	1.1	0.4	0.4	0.4	0.4	0.4	0.5
6.18A	1.1	1.1	1.2	0.4	0.4	0.5	0.5	0.5	0.5
7.41A	1.1	1.2	1.3	0.5	0.5	0.5	0.5	0.5	0.5
4.94NA	1.0	1.0	1.1	0.4	0.4	0.5	0.4	0.4	0.5
6.18NA	1.1	1.2	1.3	0.5	0.5	0.5	0.5	0.5	0.5
7.41NA	1.3	1.3	1.4	0.5	0.5	0.5	0.5	0.5	0.6

Unlike the impact of grazing intensity on TN losses, higher grazing intensity increased TP losses from the watershed. When no VFS was present in the watershed, the TP losses ranged from 0.6 to 1.3 kg/ha/year for no grazing and optimum grazing conditions, while TP losses ranged from 0.8 to 1.4 kg/ha/year for overgrazed conditions. The impacts of VFS on TP losses were similar for VFS ratios of 42 and 76 where TP losses were reduced by 43.4–68.1% compared with the baseline scenario. Nutrient inputs from manure are usually based on meeting the N-demand of pasture; phosphorus inputs thus generally exceed the P requirement for plant growth [47,63]. Since phosphorus is easily attached to soils and transported in both soluble and sediment attached forms, high stocking rates can result in greater erosion and TP losses. Similarly, TP losses increased with increasing litter application rates. TP losses were slightly greater for summer application than for fall application due to greater precipitation and higher soil temperature, which makes phosphorus more easily attach to soils [64]. For all types of grazing management and VFS ratios, TP losses for alum-treated litter application in spring ranging from 0.3 to 0.9 kg/ha/year were less than those for the baseline (0.98 kg/ha/year). Moore [57] found that poultry litter amended with alum reduces the availability of soluble P, thus reducing the runoff losses from pasture areas.

### 3.2.2. Under Future Climate Conditions (2010–2069)

Table 8 summarizes the simulation results of 172 pasture management combinations under the historical climate condition, no climate change condition and six climate change conditions. Among those 171 pasture management combinations, the best pasture management combinations that result in the least pollutant losses were selected to show the maximum pollutant reduction by comparing with the water quality improvement brought by current pasture management (Table 8). The annual average TN and TP losses under different climate conditions were within a similar range of 2.4–6.5 kg/ha and 0.3–1.9 kg/ha, respectively. However, the annual average TSS losses under the no climate change condition were similar to those under historical climate conditions with a range of 127.1 and 224.3 kg/ha, while the TSS simulations under climate change conditions, ranging from 1,085.1 to 1,772.2 kg/ha, were significantly greater than the historical annual average TSS losses.

Kay [13] compared the uncertainty sources for future climate change impacts on flood frequency in England and suggested that the uncertainty in GCMs is the major source of uncertainty in model results. The increasing magnitude of TSS losses under future climate conditions might be influenced by the uncertainty of GCM. Moreover, as extreme precipitation events increase in future climate conditions, the magnitude of peak flows were projected to increase, resulting in increases in catchment nutrient and sediment export [65–68]. Woznicki [67] also determined that a significant change in BMP performance occurred between the current climate and future climate scenarios. Our findings suggest that future climate change could significantly impact TSS losses more than nutrient losses.

Those 172 pasture management combinations under no climate change and future climate conditions revealed similar patterns as the simulations under historical climate conditions (Figure 3). Under the CCSM\_M condition, the TSS simulation results were the highest among other climate change conditions, ranging from 1,686.5 to 1,772.2 kg/ha. The TSS simulation results under the CGCM\_S condition were the least among other climate change conditions, ranging from 990.9 to

1,066.6 kg/ha. For these three GCMs, the mid-term (2040–2069) climate conditions with more precipitation resulted in greater TSS losses than the short-term (2010–2039) climate conditions.

**Table 8.** Range of 172 simulated pasture management performance under historical and various climate change scenarios (Note: NCC denotes no climate change condition; Difference denotes the difference between minimum and baseline simulation results).

	Historical climate	NCC	CCSM_S	CCSM_M	CGCM_S	CGCM_M	GFDL_S	GFDL_M
Baseline	167.9	157.7	1,108.2	1,715.3	1,036.5	1,166.4	1,169.7	1,443.1
TSS Min	127.1	129.9	1,085.1	1,686.5	990.9	1,143.6	1,148.0	1,424.4
(kg/ha) Max	224.3	198.5	1,155.9	1,772.2	1,066.6	1,202.2	1,196.7	1,464.7
Difference (%)	−24.3	−17.6	−2.1	−1.7	−4.4	−2.0	−1.9	−1.3
Baseline	3.7	3.7	3.4	4.3	3.7	3.9	3.9	3.4
TN Min	2.4	2.7	2.6	3.3	2.8	3.0	2.9	2.6
(kg/ha) Max	6.5	6.0	4.7	5.9	5.8	5.7	6.1	5.2
Difference (%)	−34.6	−28.6	−22.2	−22.6	−25.9	−23.8	−25.5	−24.4
Baseline	1.0	1.1	1.0	1.2	1.0	1.1	1.0	0.9
TP Min	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
(kg/ha) Max	1.4	1.8	1.5	1.9	1.5	1.7	1.6	1.5
Difference (%)	−68.6	−74.7	−72.5	−72.5	−72.2	−72.6	−72.5	−70.1

**Figure 3.** Changes in performance of 172 pasture management scenarios under historical climate and future climate conditions (Note: NCC denotes no climate change).

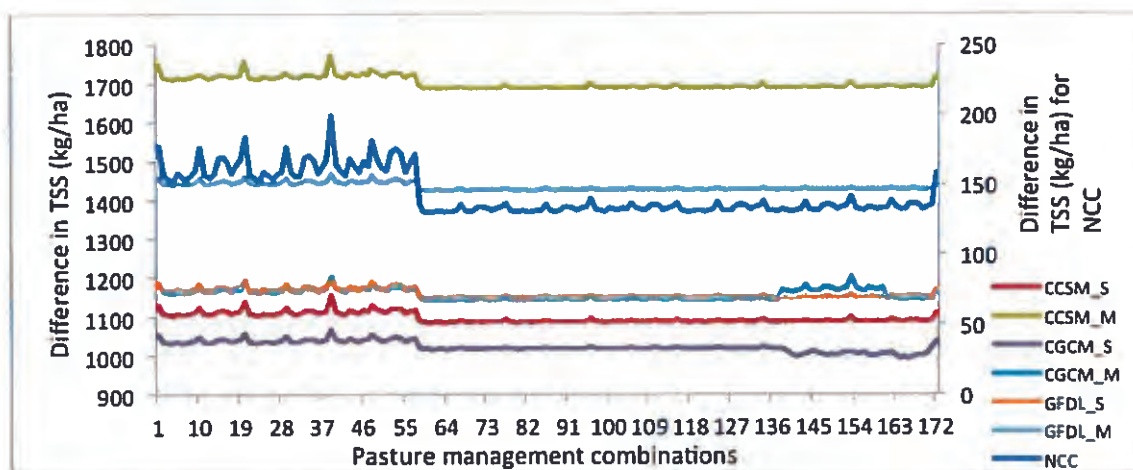
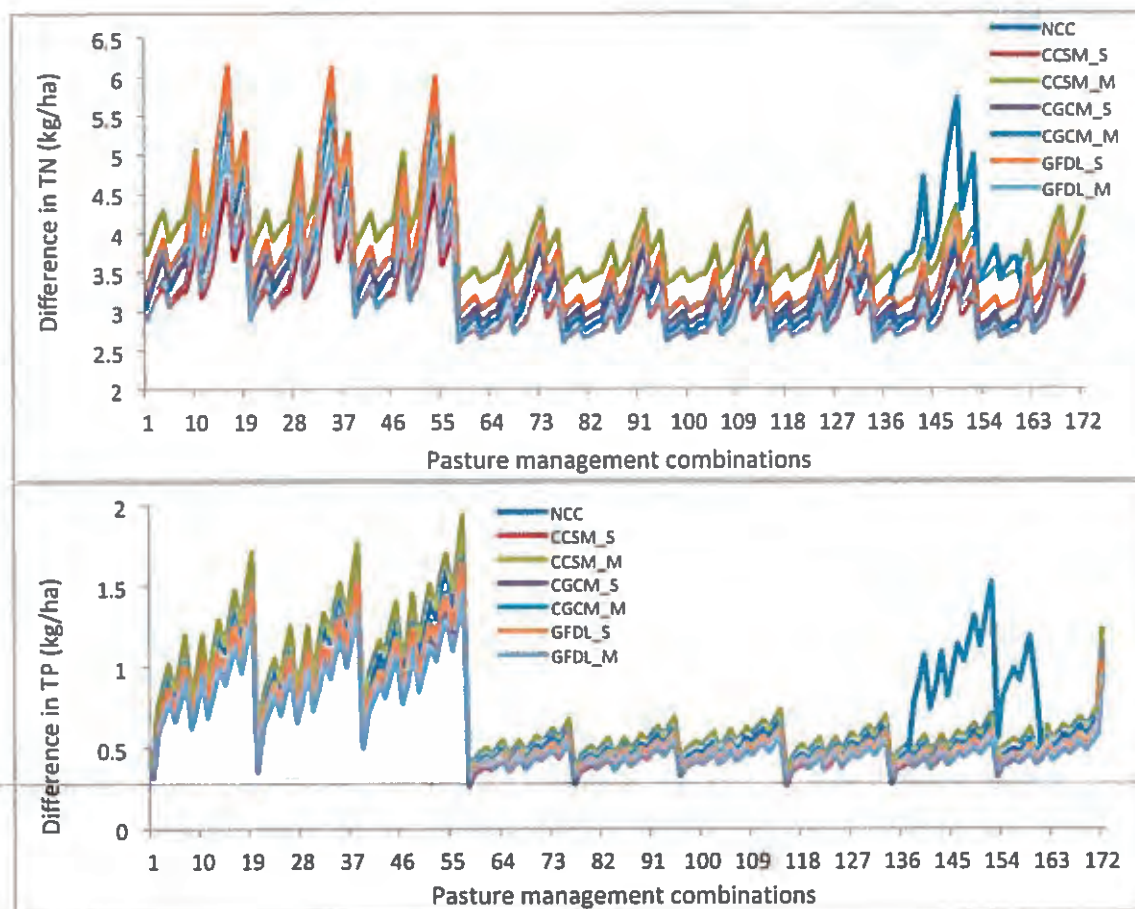


Figure 3. Cont.



The best pasture management combination performs better than the current pasture management under historical and no climate change conditions in terms of the least TSS losses (127.1–129.9 kg/ha) and the greatest TSS reduction (17.6%–24.3%) (Figure 4). The impact of climate change on nutrient losses was expected in other studies [68,69]. Van Liew [68] concluded that TN and TP losses under the future climate scenarios are projected to be about 1.2–1.9 times and up to 1.7 times, respectively greater than the baseline for two watersheds in Nebraska. Unlike the impact of climate change on TSS losses, climate change only slightly impacted TN losses, in comparison with the simulated TN losses for the current pasture management (scen172) range of 3.4 to 4.3 kg/ha under historical and future climate change conditions. Moreover, the minimum and maximum TN losses among these 171 pasture management combinations ranged from 2.4–3.3 kg/ha and from 4.7–6.5 kg/ha, respectively, for all climate conditions. Among these climate conditions, the same best pasture management combination results in better efficiencies under the historical climate condition than under the future climate change condition. The TN reduction generally ranged from 22.2% to 25.9% for all climate change conditions. Under the CCSM and CGCM conditions, the best pasture management combination performed better in the short-term (2010–2039) than in the mid-term (2040–2069) (Figure 4). Changes in the performance of the best pasture management differ under the GFDL condition. The impact of climate change on TP losses was even smaller than that on TN losses. The TP simulations ranged from



0.9–1.2 kg/ha for the current pasture management under all climate conditions. The TP improvement from the best pasture management ranged from 68.6 to 74.7%, which is greater than TSS and TN improvements. Similar to the impact of CCSM and CGCM climate conditions on TN losses, TP losses were greater in the mid-term (2040–2069) than in the short-term (2010–2039) (Figure 4). The mid-term impact of climate change on nutrient losses was greater than the short-term impact for the Lincoln Lake watershed. Wu [70] suggested that three greenhouse gas emission scenarios (B1, A1B, and A2) for 2040 through 2069 would result in decreases in precipitation ranging from 8.5 to 9.0% and increases in air temperature ranging from 1.9 to 3.1 °C. Under these climate conditions, hydrological components in the semiarid James River Basin in the Midwestern United States could be altered considerably. Their results highlight possible risks of drought, water supply shortage, and water quality degradation in this basin. Zhang [69] also found that the simulated annual TP load shows an insignificant increasing trend with the change rate of 3.77 t per decade.

**Figure 4.** Comparison of TSS, TN and TP under different climate conditions with selected BMPs and current BMPs.

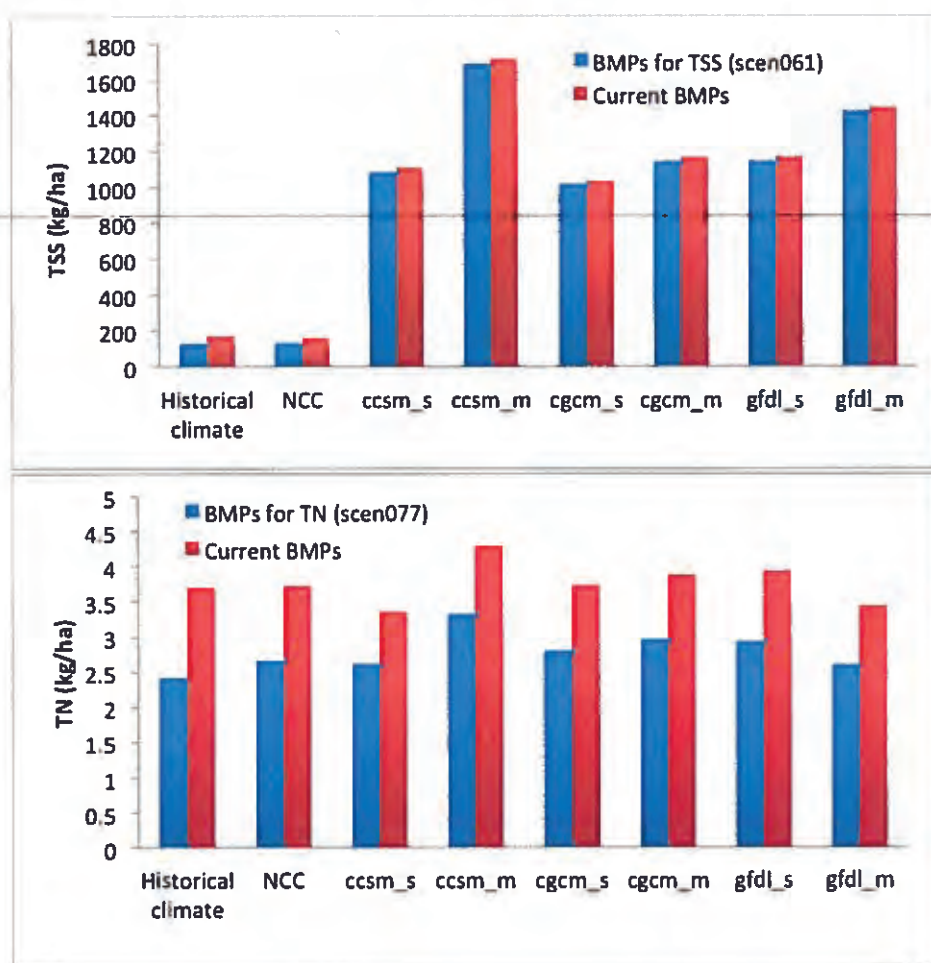
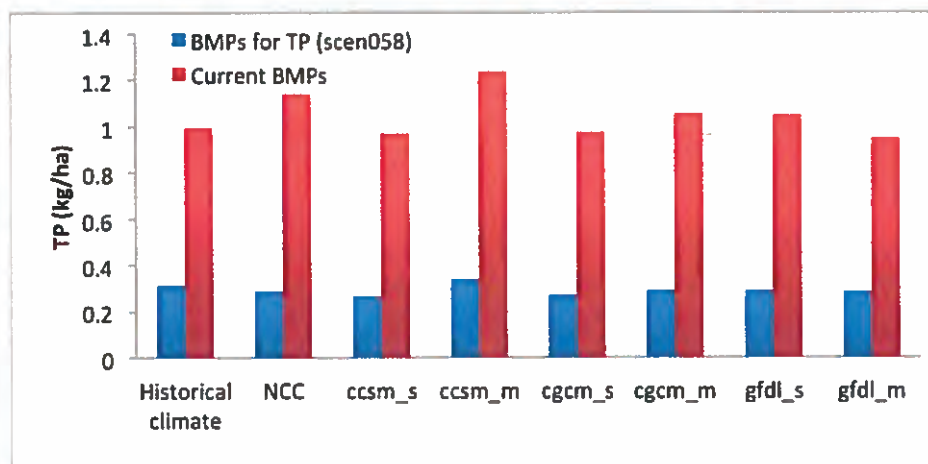


Figure 4. Cont.



### 3.3. Hindcast of Cumulative Pollutant Losses from the Watershed

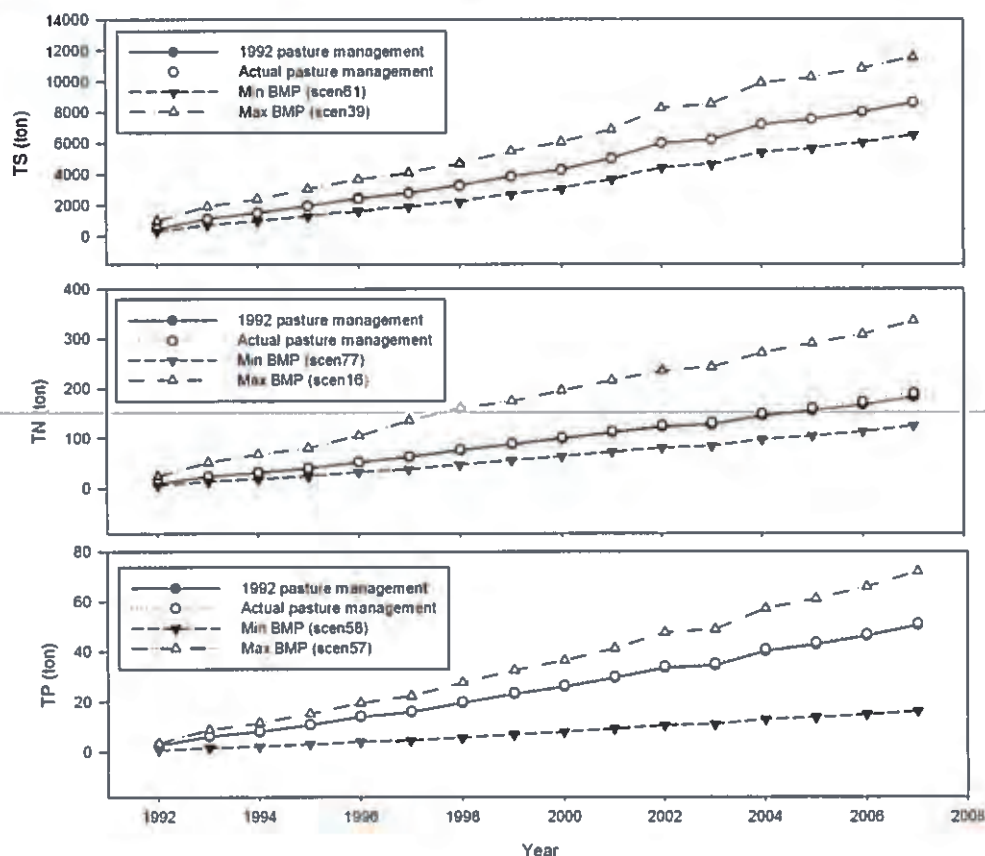
Despite the use of CEAP watersheds in several studies to evaluate the advantages of existing conservation practices [8,9,71], few of them evaluated how much conservation practices improved water quality. Especially for watersheds where only a small portion of the watershed area is managed with conservation practices, exactly how conservation practices affect water quality remains unclear [72]. Application of watershed models in evaluating certain conservation practices in past periods provides information on the effectiveness of such practices. However, assuming a constant land condition during the simulation period can increase the uncertainty of the effectiveness of conservation practices [8,73]. During the evaluation of conservation practices in the Upper Mississippi River Basin, a previous study developed a no-practice scenario to compare with the baseline scenario which includes conservation practices based on farmer survey information [1]. The difference between these two scenarios represents the cumulative benefits of conservation practices currently implemented in the watershed. Possible uncertainty in this measure in terms of the effectiveness of conservation practices is expected because the no-practice scenario was a technological step backward of conservation, and does not fully represent the previous era when conservation practices were not used.

Figure 5 shows the cumulative total suspended sediment (TSS), total N (TN) and total P (TP) losses from the watershed from 1992–2007 for four management practice scenarios. The management practices, which had the maximum and minimum cumulative constituent losses in 2007, were selected and compared with the current pasture management scenario (baseline), which is dynamic pasture management practices from 1992 to 2007, as well as the 1992 pasture management scenario, which is assumed that pasture management practices remained the same from 1992 until 2007. Details of the 1992 pasture management can be found in Chiang [27].

With insufficient nutrient supply to plant growth, less vegetated cover resulted in greater sediment losses. Higher stocking rates could result in greater sediment losses due to a decrease in infiltration of soils and an increase in soil compaction. Overgrazing should thus be avoided to reduce sediment losses from a watershed. Vegetated filter strips with a lower VFS ratio are more effective in reducing sediment losses than VFS with a greater VFS ratio. Therefore, if the best management practice

combination had been implemented in 1992, a 2,104 tons cumulative TSS reduction would have been achieved by the end of 2007 compared to the baseline scenario (8,646 tons). However, sediment losses would have increased by 2,904 tons if the worst management practice combination were implemented. The cumulative TSS losses for the baseline and 1992 pasture management scenarios were similar, primarily due to that negative impacts of urbanization masked the positive impacts of conservation practices in the watershed [27].

**Figure 5.** Cumulative pollutant losses for 1992 pasture management, actual pasture management (baseline), minimum and maximum pollutant losses scenarios at the Lincoln Lake watershed over the period 1992–2007.



Based on the previous comparison of 171 management practice scenarios, TN decreased with the intensity of grazing due to less nitrogen returned via feces and urine by cattle than with the nitrogen in the pasture consumed by the cattle. Additionally, TN losses increased with greater litter application rates, and TN losses incurred for alum-treated litter applications were slightly greater than untreated litter application. If the worst case scenario were implemented since 1992, the nitrogen losses would have increased by 144.3 tons by 2007 compared with the baseline scenario (190.6 tons), while the best management practice combination would have reduced TN losses by 65.9 tons. The cumulative TN losses (182.7 tons) for the 1992 pasture management scenario were slightly lower than the baseline scenario, indicating that TN losses would have been reduced if the pasture management remained the

same as in 1992. This may be owing to the fact that nitrogen input from pasture management practices increased and overrode the effects of other conservation practices applied since 1994 [27].

Similar to TN losses, TP losses increased as the litter application rates increased. Since poultry litter with alum amendment has a small fraction of soluble phosphorus, alum-treated litter resulted in less mineral phosphorus losses than the untreated litter at the same application rate. Similar to the simulation results of TSS and TN losses, a smaller VFS ratio reduced more TP. TP losses would have been reduced by 35 tons by the end of 2007 compared with the baseline scenario (51.2 tons), if the best management practice combination had been implemented since 1992. However, if the worst management practice combination had been implemented since 1992, TP losses would have increased by 20.6 tons.

### 3.4. Futurecast of Pollutant Reduction at the Sub-Basin Level

The best management practice combination for reducing each pollutant was selected to analyze the maximum pollutant reduction at the sub-basin level that would be achieved under different future climate conditions (Table 9). Generally, significant changes in performance were more commonly observed at the field scale, while most BMPs did not affect pollution reduction at the watershed outlet [67]. The pollutant reduction was calculated as the difference between the annual average losses for the best management practice scenario and the losses for the baseline scenario. A greater difference implies a greater reduction of pollutant losses. Figures 6–8 show the annual average reduction of TSS, TN and TP losses for the best management practice combinations, respectively. A darker color implies a greater reduction in pollutant losses.

**Table 9.** Annual area-weighted average pollutant losses at the subbasin level with adaptation of current pasture management and the best pasture management under historical, no climate change (NCC) and climate change conditions.

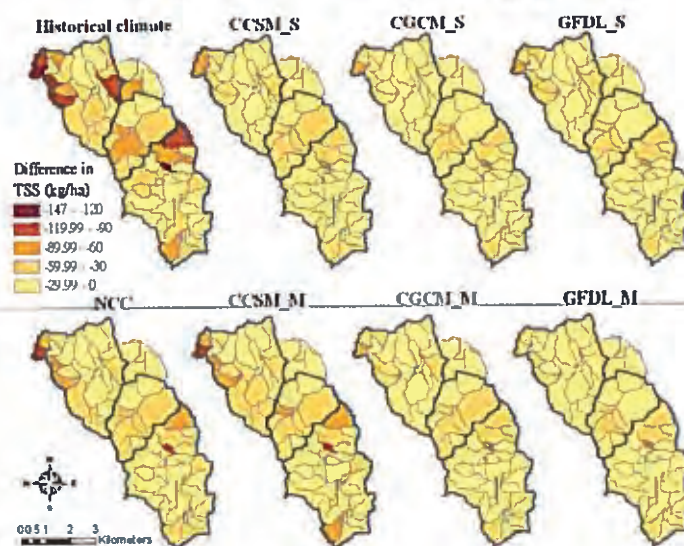
	Current	scen061	Current	scen077	Current	scen058
	TSS(t/ha)	TSS(t/ha)	TN(kg/ha)	TN(kg/ha)	TP(kg/ha)	TP(kg/ha)
Historical climate	0.16	0.12	4.00	2.70	1.05	0.34
NCC	0.16	0.13	3.85	2.83	1.19	0.32
CCSM_S	1.16	1.13	3.56	2.85	1.02	0.30
CCSM_M	1.78	1.75	4.57	3.65	1.29	0.37
CGCM_S	1.08	1.06	3.87	2.97	1.02	0.30
CGCM_M	1.21	1.19	4.00	3.11	1.10	0.32
GFDL_S	1.22	1.19	4.07	3.11	1.10	0.32
GFDL_M	1.51	1.49	3.78	2.95	1.00	0.31

The annual area-weighted average of TSS losses incurred at the subbasin level would become greater in the future climate conditions, especially in the mid-term of CCSM and GFDL conditions (Table 9). This table reveals that under historical climate conditions, more subbasins would have greater annual TSS reduction of at least 90 kg/ha with the best pasture management combination than under future climate conditions (Figure 6). Although the TSS simulations of current and best pasture management practices vary under different climate conditions, the difference between those two



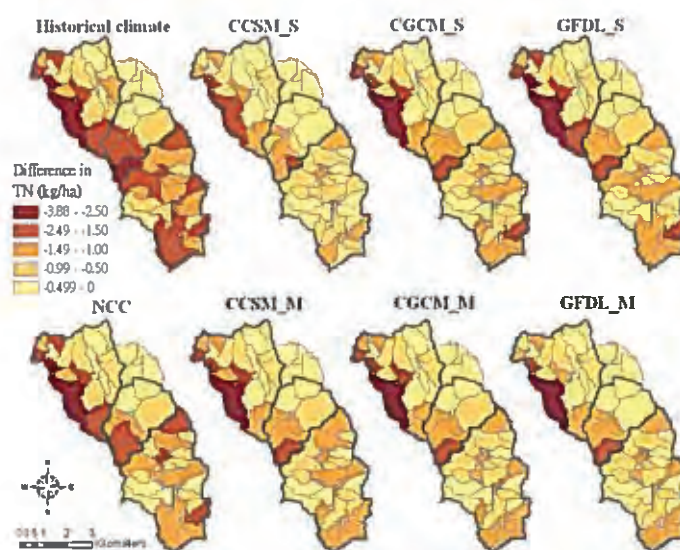
pasture management practices could provide information about which subbasins should be given priority for BMP implementation in the watershed. Simulation results indicate that more subbasins in the Beatty Branch and Lower Moores Creek subwatersheds have greater TSS reduction, indicating that the best management practice combination was more effective in reducing TSS losses in those subbasins. The subbasins where urban area was located generally had less TSS reductions because management practices were only implemented on pasture lands. The TSS reduction was the greatest in the northwestern part of the Beatty Branch subwatershed, and the southern part of the Upper Moores Creek subwatershed. The greatest TSS reduction indicated that the maximum improvement would be found if the best management practice combination (2 tons/acre alum-treated litter in spring, no grazing and VFS ratio as 42) is implemented in the future.

**Figure 6.** TSS reduction of the best pasture management combination (scen061) compared to the current pasture management for different climate conditions.



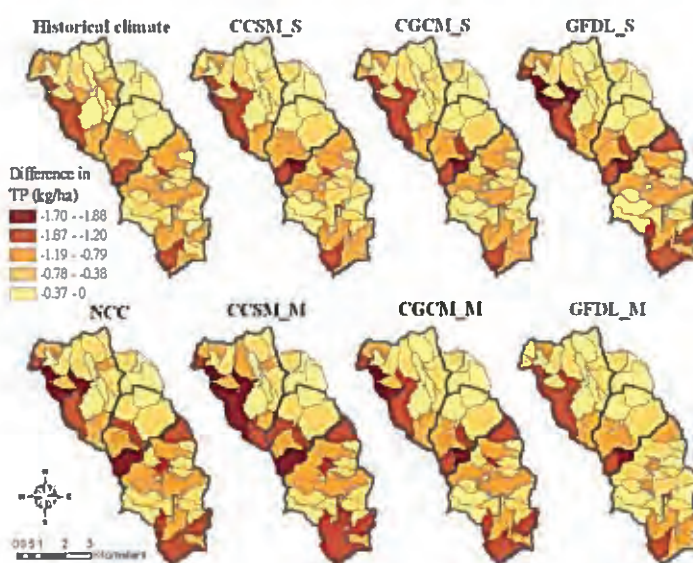
With current pasture management, only under the CCSM\_M and GFDL\_S climate conditions, TN losses were greater than the losses under the historical climate condition (Table 9). The results are consistent with the simulation results conducted by Zhang [69] in that the simulated annual  $\text{NH}_4^+\text{-N}$  load into Shitoukoumen reservoir had a significant downward trend with a decrease rate of 40.6 t per decade using the SWAT model and a GCM (HadCM3). However, simulation results indicated that TN losses with the best pasture management practices would be increased in the future climate conditions compared to its performance under the historical climate condition. This finding indicates that future climate change can impact the performance of the best pasture management practices. Wu [70] concluded that the potential climate change impact would result in decreased  $\text{NO}_3\text{-N}$  load to streams, which could be beneficial, but a concomitant increase in  $\text{NO}_3\text{-N}$  concentration due to a decrease in streamflow likely would degrade stream water and threaten aquatic ecosystems in the watershed. A greater TN reduction was found in the western part of the Beatty Branch subwatershed (Figure 7). Under the historical climate condition, reduction in TN losses ranged from 1.5 to 3.88 kg/ha in the western part of the watershed. Moreover, a greater TN reduction would have been found in the southern part of the watershed if the best pasture management practices would have been adopted.

**Figure 7.** TN reduction of the best pasture management combination (scen077) compared to the current pasture management for different climate conditions.



In the Beatty Branch subwatershed, 2–3 subbasins would have 2.5–3.88 kg/ha of TN reduction under future climate conditions, except for the CCSM\_S climate condition. The management practices impacted those subbasins under different climate change conditions in different ways, owing to dynamic nutrient management and the impacts of weather variation from 1992–2007 [5,27].

**Figure 8.** TP reduction of the best pasture management combination (scen058) compared to the current pasture management for different climate conditions.



The best management practice combination improved TP reduction in the western part of the Beatty Branch subwatershed and the southern part of the Upper Moores Creek subwatershed (Figure 8). Half of the Upper Moores Creek would have at least 0.38 and 1.19 kg/ha of TP reduction in future climate conditions. In particular, we believe that, especially for the western part of the Beatty Branch

subwatershed, critical subbasins have the best pasture management practices implemented; in addition, the greatest TP reduction would be found under the CCSM\_M condition.

#### 4. Conclusions

This study evaluated 171 pasture management combinations in the Lincoln Lake watershed for the periods 1992–2007 and 2010–2069. Due to management practices that focus on reducing different pollutants and the interactions between management practices, the best and worst management practice combinations were dissimilar for sediment, nitrogen and phosphorus. For example, overgrazing resulted in greater TSS and TP losses, but less TN losses. Intensive grazing management could increase soil compaction and decrease infiltration of soils, subsequently leading to greater TSS losses and more sediment attached P losses. Sediment losses generally decreased and nutrient losses increased with greater litter application rates. Different litter application timings influenced pollutant losses in different ways. For example, fall litter application resulted in greater TN losses while TP losses were greater for summer application. Poultry litter with alum amendment, which has a greater amount of nitrogen and less soluble phosphorus than the normal litter, resulted in greater TN losses and smaller TP losses from the watershed. Vegetative filter strips (VFS) were the most influential management practices in reducing pollutant losses, and a smaller VFS ratio (*i.e.*, the ratio of drainage area to VFS area) resulted in greater pollutant reduction.

Compared with the baseline scenario (*i.e.*, the dynamic pasture management implemented in the watershed from 1992–2007), pollutant losses would have been reduced by 2,104, 66 and 35 tons for TSS, TN and TP by end of 2007, respectively, if the best management practice combination had been implemented since 1992. The different distribution of the cumulative reduction of pollutants during the periods of 1992–2007 and 2010–2069 revealed that different amounts of pollutants would have been or will be reduced if the best management practice combinations are implemented. Generally, BMPs under the future climate change scenarios would provide sufficient nutrient load reductions that are comparable to the respective loads simulated for the current day baseline condition. The simulation results indicated that the western part of the Beatty Branch subwatershed, as well as the northern and southern parts of the Upper Moores Creek subwatershed are the critical areas that are sensitive to climate change and must implement BMPs.

BMPs are often implemented in a watershed without considering their watershed scale impacts or comparative analysis with other candidate BMPs. Without such an analysis, BMPs implemented in the watershed may not be able to meet the water quality goals. Results of this study demonstrate that watershed management should incorporate comparative analysis of various suites of BMPs, in addition to those implemented previously or under consideration for the future. With such an analysis, a watershed manager is more likely to achieve water quality goals or devise BMP implementation strategies in similar watersheds.

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### Conflict of Interest

The authors declare no conflict of interest.

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# Conservation practice effectiveness and adoption: unintended consequences and implications for sustainable phosphorus management

R. J. Dodd · A. N. Sharpley

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**Abstract** Phosphorus (P) runoff from agricultural land continues to receive attention due to a widespread lack of reduction in losses combined with a series of high profile P-induced harmful algal blooms. Many widely adopted conservation practices (CPs), aimed at reducing P loss, target particulate P (PP) through reductions in erosion or entrapment of P within the terrestrial landscape. However, there is increasing evidence that in time, these CPs may in fact increase dissolved P (DP) losses. We reviewed the effectiveness of current CPs promoted in the U.S., the results from long-term in-stream monitoring following implementation of conservation schemes and field studies investigating P loss from buffer zones designed to trap PP. These studies showed that different CPs are required to target different forms of P loss and the tendency for farmers to implement strategies targeting PP over DP resulted in an increase in dissolved reactive P export post-implementation of 37–250 % in three of the five catchment monitoring studies. Buffer zones, such as grass and vegetative filter strips, managed riparian zones and wetlands were found to accumulate labile forms of soil P over time and, in some studies, became significant sources of both inorganic and organic DP. Furthermore, often overlooked microbial processes appear to play a key role in

P release. Consequently, to improve the effectiveness of future conservation schemes, practices need to specifically target DP losses in addition to PP and recognize that CPs trapping P within the landscape are at risk of becoming legacy P sources.

**Keywords** Agricultural runoff · Conservation practices · Nutrient management · Surface runoff · Buffer zones · Water quality

## Introduction

Phosphorus (P) is an essential element for plant and animal growth and, thus, an important component of soil fertility in productive agriculture. However, diffuse losses of P from agricultural sources, while small in agronomic terms, can be environmentally significant and have been linked to the accelerated eutrophication of many streams, rivers and lakes (Carpenter et al. 1998; Smith et al. 2015b). Running alongside water quality issues, there are increasing concerns over the future supply of mineral P fertilizers (Cordell et al. 2009; Gilbert 2009), highlighting the need for more sustainable P use.

Efforts to reduce P loss from agriculture are driven by society's desire for clean, ecologically healthy waters and the large economic cost of dealing with the impacts of eutrophication. Dodds et al. (2008) estimated that on an annual basis, eutrophication costs the U.S. economy U.S.\$2.2 billion due to decreased

R. J. Dodd (✉) · A. N. Sharpley  
Department of Crop, Soil and Environmental Sciences,  
University of Arkansas, Fayetteville, AR, USA  
e-mail: rjdodd@uark.edu

recreational use of impaired waters, decreased value of waterfront properties, restoration efforts for threatened and endangered species, and providing alternative drinking water. Consequently, a suite of conservation practices (CPs) aimed at decreasing P loss from agriculture have been developed and are promoted by the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) (Table 1).

Despite significant economic investment and large scale implementation of such CPs at the field scale; however, there has been limited measured improvement in water quality at the catchment scale in both Europe and U.S. (Kronvang et al. 2005; Jarvie et al. 2013). For example, over 20 years of intensive schemes and large scale investment aimed at decreasing nitrogen (N) and P loads to the Chesapeake Bay have failed to result in major ecological improvements (Chesapeake Bay Foundation 2014; Sharpley et al. 2009b). The disconnect between reductions in P loss at the field scale and improvements in water quality at the catchment scale reflects the complexity of interactions between terrestrial soil processes, hydrological controls, in-stream P release and retention mechanisms, contributions from other non-agricultural sources, such as rural septic tanks and wastewater treatment plants, and the complex food webs in freshwater systems. Furthermore, there is growing recognition of the chronic and ubiquitous release of P from soils enriched in P as a result of past fertilization management, which buffer mitigation efforts and result in long lag times between implementation and measured improvements in water quality (Hamilton 2012; Meals et al. 2010).

The ability of soils or sediments to act as a sink for P depends on a complex mix of physical, chemical and biological processes. Changes in land management, as occurs following the implementation of CPs, alter these processes and it is unclear how this may impact soil P retention or release. For instance, many CPs focus on reduction in sediment loss and associated P via reductions in erosion or physical entrapment of nutrient-rich particulates present in surface runoff before they reach the watercourse but, do little to address dissolved P (DP) loss (Table 1). In fact, adoption of some CPs, such as no-till, have been shown to increase DP loss in some cases (e.g., Gaynor and Findlay 1995; Sharpley and Smith 1994). Similarly, accumulation of high P soil particles in critical

areas adjacent to the stream, e.g., riparian buffers zones, can decrease their effectiveness over time and even transform buffer zones from P sinks to P sources (Hoffmann et al. 2009). Characterization of the sinks and stores of P, often termed legacy P, within a catchment, and assessment of the effectiveness of CPs in dealing with legacy P sources is essential to predict the expected outcome of restoration schemes.

This paper considers the emerging challenges of reducing P loss to surface waters through agricultural management. In particular, we review current literature to assess the effectiveness of typical U.S. conservation practices investigating the following hypothesis: The lack of success of large scale conservation schemes in improving P status in sensitive catchments is, in part, due to; (1) A focus on reducing particulate (PP) losses with limited emphasis on DP loss, and (2) the widespread adoption of conservation practices which trap P within sensitive areas of the landscape which over time transition from P sinks to P sources.

### Conservation practices in the US: effectiveness for PP and DP loss at the field scale

Table 1 lists the CPs promoted by USDA-NRCS aimed at decreasing P loss from agriculture. They can be broadly split into three categories: farm inputs, source management and transport management. Source and transport measures are further categorized by USDA-NRCS as avoid, control and trap measures. Avoid measures aim to limit the loss of nutrients to runoff through reductions in the amounts of P applied and its availability in the soil, e.g., nutrient management and soil P testing, thus can generally be considered source management. Control measures target transport pathways and involve the adoption land management practices which increase infiltration, reduce runoff and erosion, e.g., adoption of no-till practices and the introduction of cover crops. The final line of defense are trap measures which physically retain nutrients and particulates in the terrestrial landscape before they reach the receiving waterbody, e.g., buffer strips, riparian corridors, wetlands.

A large volume of research has been conducted to evaluate these strategies at the field scale. Table 1 summarizes the effectiveness of the promoted CPs based on results from field trials and modelling studies

**Table 1** USDA-NCRS promoted conservation practices to minimize the loss of P from agriculture and the range of effectiveness for dissolved P (as DRP) and particulate P found in field experiments across the U.S. and Canada

Practice	Description	Effectiveness (% reduction)		References
		Dissolved P	Particulate P	
Farm inputs				
Dietary P	Match animals nutritional requirements to feed	13–89	<1	Ebeling et al. (2002) <sup>b</sup> , Ghebremichael et al. (2007) <sup>a</sup> , Hamrahan et al. (2009) <sup>b</sup> and Jokela et al. (2012) <sup>b</sup>
Corn hybrids	Use of low phytic-acid corn in feed to reduce manure P	45–48	Negligible	Leytem et al. (2008) <sup>c</sup> , Penn et al. (2004) <sup>c</sup> and Smith et al. (2004a) <sup>b</sup>
Feed additives	Addition of phytase enzyme to increase P utilization	n.s.—52	Negligible	Penn et al. (2004) <sup>c</sup> and Smith et al. (2004a, b) <sup>b</sup>
Source management/Avoid				
Nutrient management	Rate—based on soil testing, P inputs are based on crop requirements	10 % reduction for every 10 % reduction in STP	n.d.	Vadas et al. (2005) <sup>d</sup>
		>80 % reduction moving from N based to STP based litter application	Negligible	Sharpley et al. (2009a) <sup>e</sup>
		60–88 % reduction moving from N based to P based litter application	Negligible—67	Eghball and Gilley (1999) <sup>b</sup> , Miller et al. (2011) <sup>b</sup> and Sweeney et al. (2012) <sup>b</sup>
	Application timing—apply during seasons with low runoff potential	41–42	Negligible	Schroeder et al. (2004) <sup>b</sup> and Sharpley (1997) <sup>b</sup>
	Application method—incorporate, band or inject P into conservation tilled soil	20–98 <sup>1</sup>	n.s.—60 % increase	Eghball and Gilley (1999) <sup>b</sup> , Kibet et al. (2011) <sup>b</sup> , Kimmell et al. (2001) <sup>e</sup> , Little et al. (2005) <sup>b</sup> , Rotz et al. (2011) <sup>a</sup> , Tarkalson and Mikkelsen (2004) <sup>b</sup> and Sweeney et al. (2012) <sup>b</sup>
Conservation crop rotation	Sequence different rooting depth and plant acquisition mechanisms to optimize soil P uptake	85	Negligible	Smith et al. (2015a) <sup>f</sup>
Soil inversion	Reduce P enrichment in topsoil	n.s.—92	Negligible—59 % increase	Quincke et al. (2007) <sup>b</sup> , Sharpley (2003) <sup>b</sup> and Smith et al. (2007) <sup>b</sup>
Transport management/Trap				
Conservation cover	Permanent vegetative cover to increase soil infiltration and remove sediment bound P	n.s.—63	65–90	Sharpley and Smith (1991) <sup>d</sup> and Zhu et al. (1989) <sup>e</sup>



Table 1 continued

Practice	Description	Effectiveness (% reduction)		References
		Dissolved P	Particulate P	
Buffer strips/riparian zones	Slows flow, increases infiltration and removes sediment bound P	–258 to 88	35–96	Abu-Zreig et al. (2003) <sup>b,k</sup> , Blanco-Canqui et al. (2004) <sup>b</sup> , Chaubey et al. (1995) <sup>b</sup> , Daniels and Gilliam (1996) <sup>f</sup> , Dillaha et al. (1989) <sup>b</sup> , Schmitt et al. (1999) <sup>b</sup> , Lee et al. (2000) <sup>b</sup> , Lowrance and Sheridan (2005) <sup>e,k</sup>
Constructed wetlands	Removes sediment bound P	–72 <sup>j</sup> to 94	47–70	Beutel et al. (2014) <sup>e,k</sup> , Jordan et al. (2003) <sup>e,k</sup> , Kovacic et al. (2000) <sup>e,k</sup> , Maynard et al. (2009a, 2009b) <sup>e,k</sup> and Pietro and Ivanoff (2015) <sup>d,k</sup>
Transport management/Control				
Strip cropping/contour tillage/terraces	Reduces erosion and transport of sediment bound P	Negligible—53	32–91	Alberts et al. (1978) <sup>f</sup> , Gassman et al. (2006) <sup>f</sup> and Langdale et al. (1985) <sup>g</sup>
Conservation tillage	Reduces erosion and increases infiltration	–308 to –40	–33 to 96	Gaynor and Findlay (1995) <sup>f</sup> , Schreiber and Cullum (1998) <sup>e</sup> , Sharpley and Smith (1994) <sup>e</sup> , Shipitalo et al. (2013) <sup>e</sup> and Smith et al. (2015a) <sup>f</sup>
Grass waterways	Slows flow, increases infiltration and removes sediment bound P	–83 to 81	45–89	Gassman et al. (2006) <sup>f</sup> and Smith et al. (2015a) <sup>f</sup>
Drainage water management	Controls drainage to reduce outflow volumes	Negligible—68	15–31	Evans et al. (1995) <sup>d</sup> , Littlejohn et al. (2014) <sup>e,k</sup> , Tan and Zhang (2011) <sup>e</sup> and Williams et al. (2015) <sup>h</sup>

<sup>a</sup> Model simulation of P loss following implementation of a 25 % reduction in dietary P intake<sup>b</sup> Rainfall simulation experiments<sup>c</sup> Reduction in WSP content of manure as a proxy for DP loss<sup>d</sup> Review article<sup>e</sup> Edge of field monitoring<sup>f</sup> Modelling of 30 years reduction cf. baseline simulation using APEX (Edge of field) and SWAT (catchment)<sup>g</sup> Paired catchment monitoring (5 years)<sup>h</sup> Monitored tile drain outflow (subsurface pathway)<sup>i</sup> Depending on method of incorporation<sup>j</sup> Muskrat colonization in 2010 decreased effectiveness to 4 % for TP and led to a 72 % increase in DRP Release of DRP<sup>k</sup> % effectiveness measured as difference between inflow and outflow loads, *n.s.* not significant, *n.d.* not determined

across the US and Canada. Many of these studies only considered total P loss, however where P loss was separated into dissolved and particulate forms there is a clear distinction between practices which are effective at reducing DP and those more effective for PP (Table 1).

Reductions in farm inputs through careful manipulation of animal diets can reduce DP loss by up to 91 % (Ebeling et al. 2002) and following the “4 R” approach to nutrient management, which is adding P at the Right rate to match crop needs, in the Right source to ensure correct N:P balance, at the Right time to avoid application within a few days of expected rainfall, and in the Right place through incorporation into the soil profile, was highly effective at reducing DP loss (Sharpley et al. 2009b; Tomer et al. 2014). However, while in some cases reducing the rate of application reduced PP loss (Eghball and Gilley 1999) and some evidence of increased PP loss was seen when manures were incorporated with disc tillage (Eghball and Gilley 1999), the effect of reducing farm inputs and source management on PP transfer was negligible. One key guiding principle around nutrient management is to avoid the accumulation of P within the soil in excess of crop requirements. While there is clear evidence that DP losses are highly correlated with soil test P (STP) concentrations (e.g., Heckrath et al. 1995; McDowell and Sharpley 2001), a study by Withers et al. (2009) suggested the reduction of STP in P enriched soils will have limited impact on PP loss because STP represents only a small proportion of the total P present in soils.

Transport measures, and strategies aimed at minimizing erosion (e.g., conservation tillage, cover crops) and trapping sediment (e.g., buffer strips) were the most effective at reducing PP loss (Table 1). However, the impact on DP was highly variable and implementation of these CPs actually increased the loss of DP in many studies and by more than 200 % for both vegetative buffers and conservation tillage.

#### Implementation at the catchment scale

The effectiveness of USDA-NCRS recommended CPs has been demonstrated at the field scale but does this relate to improvements in instream water quality? Table 2 summarizes the results from six long-term monitoring studies designed to assess the impact of implementing a range of different conservation

practices on P transport to sensitive waterbodies. In the majority of the studies the implemented CPs targeted PP loss, although nutrient management was common to all but one. Significant reductions in TP loading were observed at four of the six sites and during the first 20 years of monitoring in the Lake Erie Basin. However, this appears to be mostly due to a reduction in PP loss and, where measured, the adoption of cover crops, vegetated buffer strips and no till reduced PP loads by 29–70 %. Conversely, DP loading was only reduced in the Cannonsville Reservoir Basin (Bishop et al. 2005) and during the first 20 years of monitoring in the Lake Erie catchment (Richards et al. 2002). In the other studies dissolved reactive P (DRP) loading actually increased over the monitoring period.

Reductions in DP loading in the Cannonsville Reservoir Basin were attributed mainly to improved nutrient management (Bishop et al. 2005). Infrastructure improvements including construction of a manure storage lagoon and improvements in roadways allowed more strategic application of manure in terms of timing, rate and more even distribution to fields further from the watercourse. Similarly the 85 and 88 % reduction in DRP within the Sandusky and Maumee Rivers between 1975 and 1995 was attributed to assumed reductions in P fertilizer inputs indicated by 25–40 % reduction in sales between 1980 and 1995. These reductions in DRP back up the results from field trials reviewed in Table 1 which indicate that nutrient management is the most effective strategy to decrease DP loss.

While some form of nutrient management was involved in all of the conservation schemes implemented in Table 2 this did not result in decreases in DRP loading in four of the six catchments and DRP loads were increased in three of the four catchments, where it was determined. Clearly, the type of agriculture appeared to have an effect on the effectiveness of strategies. Brannan et al. (2000), found that the implementation of CPs which mainly targeted PP, through erosion control and particulate trapping, reduced PP by 70 % ( $2.09\text{--}0.63\text{ kg P ha}^{-1}$ ) in the arable dominated catchment but only by 35 % ( $4.59\text{--}3.00\text{ kg P ha}^{-1}$ ) in the dairy dominated catchments, while DRP loading was increased to a greater extent in the arable catchment with a 52 % increase for dairy from  $1.03$  to  $1.57\text{ kg P ha}^{-1}$  and a 250 % increase for arable from  $0.10$  to  $0.35\text{ kg P ha}^{-1}$ . While

**Table 2** Reduction in total, dissolved and particulate P loads found in U.S. catchment monitoring schemes following the implementation of a range conservation practices

Study	Location	Receiving catchment	Major land use	CPs implemented (main target) <sup>a</sup>	Study type (duration)	% Reduction		
						TP	PP	DP
Bishop et al. (2005)	Cannonsville Reservoir Basin (NY)	Cannonsville Reservoir	Dairy pasture and crop	Manure management (DP) Rotational grazing (PP) Drainage management (DP) Crop management (PP)	Paired catchment study. Pre- versus post-implementation monitoring (2 years pre-, 5 years post-)	n.d.	29	TDP: 43
Brannan et al. (2000)	Owl Run Watershed (VI)	Chesapeake Bay	Dairy pasture and crop	Manure management (DP) Stream fencing (DP + PP) Cover crops (PP) Field strip cropping (PP) Grass waterways (PP)	Pre- versus post-implementation monitoring (3 years pre-, 7 years post-)	Catchment outlet 25 Dairy dominated sub-catchment	54 35	TDP: 23 (DRP: -37, DUP: 66) TDP: 4 (DRP: -52, DUP: 54)
Inandar et al. (2001)	Nomini Creek (VI)	Chesapeake Bay	Crop	Nutrient management (DP) No-till (PP) Filter strips (PP) Stabilization structures (PP)	Pre- versus post-implementation monitoring (3 years pre-, 7 years post-)	Crop dominated sub-catchment 36	70	TDP: -117 (DRP: -250, DUP: -78)
Lemke et al. (2011)	Mackinaw River (IL)	Gulf of Mexico	Crop	Grass waterways (PP) Field buffers (PP) Strip-tillage (PP)	Paired catchment (7 years)	n.s.	n.d.	DRP: n.s.
						4-21	30-41	TDP: -61-86 (DRP: -92, DUP: -83 to -55)

Table 2 continued

Study	Location	Receiving catchment	Major land use	CPs implemented (main target) <sup>a</sup>	Study type (duration)	% Reduction		
						TP	PP	DP
Locke et al. (2008)	Beasley Later Watershed (MS)	Beasley Lake	Crop	Controlled drainage (DP) Field buffers (PP) Riparian forest planting (PP)	Lake monitoring (12 years)	4	n.d. (SS: 70)	n.d.
Richards et al. (2002)	Sandusky River (OH)	Lake Erie	Crop	Nutrient management (DP) Conservation Tillage (PP)	River monitoring 1975–1995 (20 years)	Sandusky River 46	n.d.	DRP: 88
	Maumee River (OH)					Maumee River 42	n.d.	DRP: 85
Daloğlu et al. (2012)	Sandusky River (OH)				River monitoring 1995–2008 (13 years)	Sandusky River n.d.	n.d.	DRP: 70
Michalak et al. (2013)	Maumee River (OH)					Maumee River –58	–31	DRP: –218

<sup>a</sup> Based on expected effectiveness for each P form taken from Table 1, n.s. not significant, n.d. not determined, TP total P, PP particulate P, TDP total dissolved P, DRP dissolved reactive P, DUP dissolved unreactive P, SS suspended sediment



these loadings are relatively low, DRP, which is more bioavailable than PP, made up a much greater proportion of TP post CP implementation in both the arable catchment, increasing from only 4 to 21 % and the receiving river, increasing from 15 to 46 %. Although nutrient management was implemented, manure application rates in the arable fields were based on nitrogen requirements and were in excess of crop P requirements which may in part explain the large increase in DRP export. Interestingly export of TDP was not increased to the same extent as DRP. As part of nutrient management manure storage lagoons were constructed to allow for strategic timing of application. Conversion of organic P within manure to orthophosphate during storage was suggested as a potential reason for the reduction in organic P loads and increase in DRP. Thus, the role of biotic processes in influencing P availability are rarely considered, but add to the complexities of P source management and system response.

Information from the long-term monitoring of the Sandusky and Maumee Rivers in Ohio, major tributaries of Lake Erie is particularly enlightening. Implementation of CPs within these catchments dramatically reduced DRP and TP loads by more than 80 and 40 % respectively between 1975 and 1995, and in stream flow weighted mean concentrations of DRP decreased from 0.06 and 0.175 mg P L<sup>-1</sup> in 1995, to 0.015 and 0.03 mg P L<sup>-1</sup> in 2008 (Richards et al. 2002). These reductions corresponded with a reduction in P fertilizer inputs, as discussed earlier, and an increased adoption of no-till cultivation from virtually zero in 1975–50 % of cropland in 1995. However, despite these initial improvements, P loading, especially DRP, increased from 1995 onwards; and was 70 and 218 % larger in 2008 compared to 1995 in the Sandusky and Maumee Rivers, respectively. Furthermore annual P loads in the Sandusky River were between 350 and nearly 500 kg P year<sup>-1</sup> in 2006–2010, which is greater than prior to restoration efforts in 1995, when the annual P load was around 200 kg P year<sup>-1</sup> (Daloglu et al. 2012). Record breaking algal blooms in Lake Erie have occurred in recent years (Wynne et al. 2013). The most recent of which, in the summer of 2014 resulted in a 2 day shutdown of the City of Toledo's water supply to almost half a million people (Henry 2013; New York Times, August 2014). Modelling analysis of the long-term trends in water quality and changes in land

management have implicated the widespread adoption of conservation tillage and broadcast application of fertilizer and manure during fall and winter, without incorporation, as contributors to the increased P loadings (Daloglu et al. 2012; Michalak et al. 2013; Smith et al. 2015a).

Conservation tillage imparts many benefits to the soil, including improving soil health and quality (Karlen et al. 2003, 2014; Sims et al. 1997). However, long-term surface application of P fertilizers and manures in the absence of conventional tillage can lead to accumulation of P in the soil surface (e.g., Cade-Menun et al. 2010; Mathers and Nash 2009; Vu et al. 2010) and encourage the formation of preferential flow paths (Shipitalo et al. 2000). Consequently conservation tillage has been shown to increase DP losses over time (e.g., Gaynor and Findlay 1995; Sharpley and Smith 1994) and may in fact increase PP loss, despite a reduction in erosion and sediment loss due to P enrichment of the particles transported (Gaynor and Findlay 1995). Therefore, management of P application must be adapted to minimize the potential for surface soil accumulation of P (Joosse and Baker 2011; Sharpley et al. 2012).

#### Adoption of conservation practices

Results from field trials and long-term catchment monitoring clearly show that different CPs are more effective against different forms of P loss and reductions in DP appear to be especially challenging. The main strategy effective at reducing off-farm DP loss is nutrient management (see Table 1), however, it appeared to have limited impact at the catchment scale (Table 2). In addition to the confounding impact of other conservation practices adoption rates play an important part in the success of conservation schemes. Insights into CP adoption and farmer CP decision making have recently been gained through reviewing the National Institute of Food and Agriculture (NIFA) Conservation Effects Assessment Project (CEAP) setup to assess the effectiveness of CPs on water quality across 13 impaired catchments throughout the US. Nutrient management plans were generally disliked by farmers mainly due to distrust around recommendations and a tendency to favor “insurance fertilization” (Osmond et al. 2015). As a result nutrient management plans were generally not fully implemented and in some cases, even after soil testing,

corresponding fertilizer recommendations were not followed.

In contrast, practices which targeted sediment and therefore PP loss, namely conservation tillage, grassed waterways and terraces, were most widely adopted, regardless of whether dissolved or particulate pollutants were of most concern (USDA-NCRS 2012). Discussions with farmers have indicated that they are more likely to address water quality issues for pollutants they can see, i.e., sediments than invisible dissolved pollutants (Reimer et al. 2012) explaining the preference for erosion control measures.

In one catchment successful and widespread adoption of nutrient management was achieved but only following the hiring of a dedicated extension officer, highlighting the importance of farmer education and outreach (Osmond et al. 2012, 2015).

In summary, long-term monitoring has highlighted the limited impact and even negative effects of catchment scale implementation of CP on DP loss. Limited implementation of nutrient management plans and an adoption preference for strategies targeting PP over DP along with confounding effects of some of the practices actually increasing DP loss supports our hypothesis that a focus on PP over DP losses is in part responsible for the lack of success of many catchment scale conservation schemes.

### Conservation practices increasing P loss: transitions from P sink to P source

Our second hypothesis relates to the unintended consequences of implementing CPs leading to increases in P loss. In addition to the potential negative impacts of adopting conservation tillage discussed above, strategies which focus on the trapping sediment (and associated PP) prior to it reaching the watercourse will gradually accumulate P within the landscape. We hypothesize that over time, vegetative filter strips and riparian buffers, wetlands and grassed waterways will become hotspots of legacy P and have the potential to transition from P sinks to P sources.

The speciation of P accumulating within these areas will depend in part on that of the upslope soils. The more labile soil P forms have been shown to accumulate in the clay size fraction of the soil. For example, following long-term fertilization, Leinweber et al.

(1997) found that resin P concentrations were highest in the clay fraction, while  $\text{H}_2\text{SO}_4\text{-P}$ , associated with Ca-P forms and residual P accumulated in the silt and sand fractions respectively. Similarly for organic P ( $\text{P}_o$ ), diester and labile monoester phosphates dominated the clay fraction while the more strongly retained inositol phosphates (including phytate-P) mainly accumulated in the sand fraction (McDowell and Stewart 2006). Smaller particles, mainly clays and silts, are selectively eroded during surface runoff and are often transported further than larger, heavier particles, like sand (Sharpley 1985). This selective transport suggests that there would be preferential accumulation of more labile PP within the transition zones. However, finer particles are less prone to deposition and may, thus, remain suspended in runoff and pass straight through these zones with little retention (Owens et al. 2007).

Further complication arises from the potential transformations occurring due to different physiochemical, biological and environmental conditions, such as increased carbon addition from vegetation and leaf litter in riparian zones, wetlands and grassed waterways and changes in redox conditions as a result of periods of inundation, add layers of complexity when considering the long-term impact of CPs which trap P in the landscape.

Buffers, such as grass (GFS) or vegetated filter strips (VFS), managed riparian zones and constructed wetlands, provide a disconnect between the edge-of-field and the watercourse. These areas function by slowing the flow of surface runoff, promoting sedimentation and infiltration, to act as a filter trapping sediment and removing DP through plant uptake (Hoffmann et al. 2009).

Experiments in the U.S. have shown that buffers and wetlands can be highly effective at reducing PP loss at the field scale but, the impact on DP appears highly variable and can in fact increase DP loss (Table 1).

Table 3 provides a summary of field studies assessing the impact of buffers on P loss. All but one of the 16 buffer filter strips and all but two of the five wetlands studies showed a significant reduction in TP loss in surface runoff. The difference in TP load between sites with buffers and sites without ranged from 21 to 96 % and the difference between inflow and outflow TP loads from wetlands ranged from 17 to 80 %. For DP, however, the impact was much more

Table 3 Impact of buffers, wetlands and grass waterways on total P (TP), particulate P (PP) and dissolved reactive P (DRP) losses from field experiments

Study design (location)	Design details	Time since implementation (years)	Additional comments	% Reduction				Reference			
				Runoff	TP	PP			DRP		
						Volume	Conc		Load	Conc	Load
Grass, vegetated and riparian buffers	Runoff plot experiment under natural rainfall (U.S. TN)	2		39–64	n.s.	68–76	n.s.	66–82	n.s.	66–73	Al-wadaiy et al. (2012)
	Runoff plot experiment under simulated rainfall (U.S. MO)	1		11–15	n.g.	n.g	n.g.	36–53	n.g.	37–54	Blanco-Canqui et al. (2004)
	Edge of field monitoring (IT)	4		78	22	81	n.d.	n.d.	n.s.	83	Borin et al. (2005)
	Runoff plot experiment under simulated rainfall (U.S. AR)	1		n.g.	67–97	43–90	n.d.	n.d.	68–96	40–88	Chaubey et al. (1995)
	Runoff plot experiment under simulated rainfall (U.S. VT)	6	6 simulated rainfall runs	20–84	n.g.	67–95	n.g.	68–96	n.g.	–31 to 79	Dillaha et al. (1989)
				–19 to 71	n.g.	34–91	n.g.	36–93	n.g.	–258 to 60	
	Runoff and drainage plot experiment under natural rainfall (Ca)	1		35–40	n.g.	85–86	n.d.	n.d.	n.g.	50–67	Duchemin and Hogue (2009)
				–18 to 8	n.g.	–418 to –345	n.d.	n.d.	n.g.	–33	
				15	n.g.	76	n.d.	n.d.	n.g.	22–33	
	Runoff plot experiment under simulated rainfall (U.S. IA)	4		7–21	n.g.	46–93	n.d.	n.d.	n.g.	28–85	Lee et al. (2000)
Edge of field monitoring. Outflow compared to inflow. (U.S. GA)	3 zone buffer	4		68	n.s.	67	n.s.	56	n.s.	62	Lowrance and Sheridan (2005)
				66	49	67	71	56	44	64	
				44	n.s.	80	43	63	8	79	
	Runoff plot experiments with natural rainfall. (FI and S)	7		15	n.g.	38	n.d.	n.d.	n.g.	14	Uusi-Kämpä et al. (2000)
		7		n.s.	n.g.	27	n.d.	n.d.	n.g.	–64	
		3		–71	n.g.	–37	n.d.	n.d.	n.g.	–33	
	Edge of field monitoring. (F)	9	CT	20	n.g.	36	n.g.	44	n.g.	7	Uusi-Kämpä and Jauhainen (2010)
		9	CT+3 G	10	n.g.	13	n.g.	10	n.g.	18	
		9	CT+3 G+2 DD	1	n.g.	14	n.g.	23	n.g.	8	
VFS-vegetation remains		9	CT	10	n.g.	28	n.g.	48	n.g.	–60	
		9	CT+3 G	16	n.g.	21	n.g.	–7	n.g.	36	
		9	CT+3 G+2 DD	30	n.g.	23	n.g.	28	n.g.	23	

Table 3 continued

Study design (location)	Design details	Time since implementation (years)	Additional comments	% Reduction				Reference			
				Runoff	TP	PP		DRP	Conc	Load	
						Volume	Conc				
Edge of field monitoring (NL)	GFS-grass harvested	3–4	Shallow sub-surface flow Deep subsurface flow Tile drained	n.g.	n.g.	61	n.g.	62	n.g.	62	Noiji et al. (2013)
				n.g.	n.g.	n.s.	n.g.	n.s.	n.g.	n.s.	
				n.g.	n.g.	n.s.	n.g.	n.s.	n.g.	n.s.	
Constructed wetlands											
Wetland treats agricultural irrigation water, measured difference between inflow and outflow (U.S. WA)	Sediment basin connected to 2 surface flow wetlands (Total area: 1.6 ha)	7	Sediment basin (year 1/year 7) Wetland 1 (year 4/year 7) Wetland 2 (year 4/year 7)	n.d.	18/16	n.d.	n.d.	n.d.	13/29	n.d.	Beutel et al. (2014)
				n.d.	46/30	n.d.	n.d.	n.d.	70/36	n.d.	
				n.d.	36/29	n.d.	n.d.	n.d.	70/24	n.d.	
Wetland treats drainage from an agriculturally dominated catchment, difference between inflow and outflow (U.S. MD)	1.3 ha restored catchment scale wetland	11		n.g.	n.g.	–11 to 59	n.d.	n.d.	n.g.	–18 to 53	Jordan et al. (2003)
Wetland treats drainage from farm tile drains, difference between inflow and outflow (U.S. IL)	3 Small farm scale wetlands	3	Wetland 1 (year 1/year 3) Wetland 2 (year 1/year 3) Wetland 3 (year 1/year 3)	n.g.	n.g.	17/35	n.d.	n.d.	n.g.	17/47	Kovacic et al. (2000)
				n.g.	n.g.	80/38	n.d.	n.d.	n.g.	90/38	
				n.g.	n.g.	60/–54	n.d.	n.d.	n.g.	15/–27	
Grass waterways											
Paired catchment study—2 catchments with grass waterway, 2 without (GE)	Unmanaged waterway and annually cut waterway	5	Unmanaged Annually cut	90	n.g.	n.g.	n.g.	76	n.s.	31	Fiener and Auerwald (2009)
				10	n.g.	n.g.	n.g.	88	n.s.	n.s.	
Runoff plot experiment. Inflow concentrations compared to outflow (U.S. OH)	Simulated grass waterways	2		n.g.	n.g.	n.s.	n.d.	n.d.	15	n.s.	Shipitalo et al. (2010)
Edge of field monitoring. Before and after implementation compared (U.S. IN)	Established on ephemeral gullies	6		n.g.	n.s.	n.s.	n.d.	n.d.	–61	–478	Smith et al. (2015a)
n.d. not determined, n.g. not given, n.s. not significant											



variable. Four of the 16 buffer strips appeared to be sources of DP and load reductions ranged from  $-258\%$  (Dillaha et al. 1989) to  $88\%$  (Chaubey et al. 1995). Similarly to TP, two of the five wetlands appeared to release DP and reductions in load ranged from  $-27$  to  $90\%$  (Kovacic et al. 2000). While DP load reductions were observed in many studies, much of this impact was attributed to reductions in runoff volumes and where provided, the impact on DP concentration was often not significant (Al-wadaey et al. 2012; Borin et al. 2005; Lowrance and Sheridan 2005).

Evidence for reduction in buffer effectiveness over time was demonstrated by Dillaha et al. (1989) in a series of rainfall simulation experiments to experimental buffer plots. Increased TP loads were found between the first set of three simulated runoff events and the second set of three runoff events for all buffer plots and an increase in DRP load for three of the six plots. Hence, reductions in TP and DRP compared to the no buffer plots were much less during the second rainfall simulation and release of DRP from the buffer plots was increased (Table 3). Investigation of the effectiveness of field scale buffer zones has also shown a reduction in effectiveness over time (Table 3). The most effective buffers were between 1 and 4 years old. With the exception of one site where runoff, TP, DRP and PP losses were increased compared to a non-buffered control (Uusi-Kämpä et al. 2000), reductions in TP and DRP load in surface runoff ranged from  $43$  to  $93\%$  and  $22$ – $88\%$  respectively compared to reductions of  $13$ – $38\%$  for TP and  $-64$ – $36\%$  for DRP in buffers over 7 years old. Beutel et al. (2014) found a small decrease in TP load reductions from a constructed wetland treating irrigation runoff between years four and seven of operation and a large decrease in DRP reductions over this time from  $70\%$  in year four to only  $24$ – $36\%$  in year seven. Similarly, Kovacic et al. (2007) found reductions in effectiveness of two out of three wetlands receiving tile drainage from cropland over the first 3 years of operation, over which time one wetland became a source of DRP.

While only a limited number of studies have been conducted on grassed waterways (Table 3), unmanaged grassed waterways established for 5 years were found to decrease DRP loading by  $30\%$  in a paired catchment study in Germany as a result of reduction in runoff volume, but no significant effect on DRP

concentration was found (Fiener and Auerswald 2009). However, Smith et al. (2015a) found that grassed waterways acted as a large source of DRP in the growing season after establishment in arable fields within the Lake Erie catchment. Grassed waterways act as a direct conduit for runoff to reach the watercourse so release of P from these zones is likely to have a large impact on water quality.

### Processes controlling P release

Release of DP from buffer and wetland soils in many studies has been attributed to the accumulation of labile soil P pools. Studies comparing soil P concentrations in 10 buffer soils and one wetland soil to adjacent field soils showed a varying response in soil test P (STP) (Table 4) from no significant difference to increased and decreased concentrations. However, the bioavailable fraction, estimated through extraction with water or weak salt solutions, was dramatically increased by  $39$ – $146\%$  in all but two of the sites. While we were unable to find studies documenting the soil P concentrations in grassed waterways the large retention of PP ( $76$ – $88\%$ ) found by Fiener and Auerswald (2009) (Table 3) indicates the likely accumulation of P within these structures. Furthermore, many studies have documented the accumulation of bioavailable forms of P within agricultural drainage ditches (Nguyen and Sukias 2002; Sallade and Sims 1997; Vaughan et al. 2007).

The main mechanisms for P release from these transition zone soils is through (i) abiotic desorption and dissolution of P and a reduction in P retention due to saturation of sorption sites and (ii) biotic release following nutrient cycling through the microbial and plant pools.

Stutter et al. (2009) carried out incubation and leaching experiments to determine the importance of the different mechanisms in the remobilization of P from a range of buffer strip soils with varying STP concentrations. The addition of high P sediments to these soils, mimicking the accumulation of PP, did not decrease P sorption capacity and did not increase DRP leaching. This has been attributed to the increase in sorption sites following sediment addition along with added P. Further experiments found that manipulating conditions which promoted increased microbial activity promoted DRP release and increasing the soil temperature from  $5$  to  $20\text{ }^{\circ}\text{C}$  along with addition of P

**Table 4** Percent difference in soil P fractions in buffer and wetland soils compared adjacent agricultural fields

Source (location)	Age	STP (method)	% increase versus field soils			
			Bioavailable P (method)	DOP (method)	MBP	Reference
Riparian buffer/UK	3	n.s (Olsen)	39 % (1 mM NaCl)	23 % (1 mM NaCl)	34 %	Stutter et al. (2009)
Riparian buffer/UK	8	n.s.	146 % (1 mM NaCl)	742 % (1 mM NaCl)	227 %	
Riparian buffer/UK	n.g.	56 % (Olsen)	125 % (WSP)	155 % (WSP <sub>0</sub> )	212 %	Roberts et al. (2013)
Riparian buffer/U.S.	13	−0.43 % (Bray-1)	52 % (EPC <sub>0</sub> )	n.d.	n.d.	Schroeder and Kovar (2008)
Harvested grass buffer/FI	17	n.s.	n.d.	n.d.	n.d.	Uusi-Kämpä and Jauhiainen (2010)
Vegetated buffer/FI	15	50 % (P <sub>AC</sub> )	n.d.	n.d.	n.d.	
Riparian buffer/NZ	4–5	208 % (Olsen)	65 % (WSP)	n.d.	n.d.	Cooper et al. (1995)
Riparian buffer/NZ	4–5	−25 % (Olsen)	36 % (CaCl <sub>2</sub> -P)	n.d.	n.d.	Aye et al. (2006)
Riparian buffer/NZ	4–5	21 % (Olsen)	58 % (CaCl <sub>2</sub> -P)	n.d.	n.d.	
Riparian buffer/NZ	4–5	−32 % (Olsen)	−14 % (CaCl <sub>2</sub> -P)	n.d.	n.d.	
Wetland/NZ	4–5	−63 % (Olsen)	−50 % (CaCl <sub>2</sub> -P)	n.d.	n.d.	

rich sediments increased DRP leaching from 0.05 to 150 mg P L<sup>−1</sup>. Their findings suggest that saturation of P sorption sites had not occurred, even in the soils with the highest STP and that cycling through the microbial biomass plays an important role in remobilization of P.

This is supported by the buildup of the microbial P pool over time following establishment of riparian buffer zones and the large increase in the microbial P pool in riparian soils compared to adjacent field soils found by Stutter et al. (2009) and Roberts et al. (2013) (Table 4). The potential for microbial accumulation in drainage ditch sediments had also been demonstrated with 10–40 % of DRP reductions in fluvium experiments attributed to microbial uptake (Sharpley et al. 2007). Microbial processes play a large role in the soil organic P cycle and Stutter et al. (2009) and Roberts et al. (2013) also showed a large increase in the labile organic P fraction extracted by either 1 mM NaCl or water (Table 4). The P<sub>0</sub> fraction made up 90 % of the total P extracted with 1 mM NaCl in 8 year old VFS in the U.K. (Stutter et al. 2009) and 34 % of water extractable P in the 12 VSF soils investigated by Roberts et al. (2013), highlighting the role of P<sub>0</sub> cycling within these zones.

Of the field studies on buffer effectiveness presented in Table 3 only two studies reported total

dissolved P (TDP) concentrations (Dillaha et al. 1989; Noiji et al. 2013). In these studies dissolved unreactive P (DUP), generally considered to be mainly P<sub>0</sub>, made up 20–50 % of TDP. Similarly, in the plot study by Dillaha et al. (1989), where buffer soils increased DRP concentrations relative to no buffer plots, there was a corresponding increase in DUP concentration of a similar magnitude of up to 200 %. At the catchment scale the impact of CPs on DUP appears mixed. Dissolved unreactive P was determined for two of the six locations presented in Table 2, Owl Run (Brannan et al. 2000) and Nomini Creek (Inandar et al. 2001). In the Owl Run catchment there was a decrease in DUP export from the dairy dominated catchment which resulted in an overall, small decrease in TDP loading, but an increase in DRP loads, attributed to changes in manure speciation during storage. However, in the arable dominated catchment where transport focused CPs were implemented, including grass waterways and strip cropping, there was a significant increase in both DUP and DRP loading resulting in a 117 % increase in TDP export. The Nomini Creek catchment is dominated by row crop agriculture and implementation of transport CPs, including buffers and no-till, increased DUP loads by 55–83 %, and DRP loads by 92 %. In both catchments, DUP made up a significant proportion of TDP, ranging from 25 and 78 % in the

arable and dairy dominated catchments of Owl Run respectively and >80 % in Nomini Creek. The dominance of DUP and the bioavailability of some  $P_o$  forms to algae (Whitton et al. 1991; Whitton and Neal 2011), indicates that the impact of CPs on dissolved  $P_o$  export needs to be considered and that the potential of buffer zones to act as sources of P may be underestimated by monitoring programs solely measuring DRP.

In addition to DP, the bioavailability of PP export to waterbodies can be modified by buffer zones and wetlands. Preferential trapping of sand sized particles in buffers indicates that finer particles, which tend to be enriched with P, may remain in runoff passing through the buffer. This may be especially relevant if the physical retention properties of the buffer have been reduced due to the accumulation of sediment over time (Owens et al. 2007). Similarly spatial assessment of particulates stored within wetland soils have shown that clay particles travel further into the wetland and can accumulate near the outflow while less P rich sand particles prudentially accumulate nearer the inflow position (Maynard et al. 2009a). Transformation of PP speciation has also been documented within wetland soils with an increase in the proportion bioavailable  $P_o$  fraction found in the outflow of a constructed wetland in California compared to the irrigation water entering the wetland (Maynard et al. 2009b). This fraction was considered to be microbial in origin reinforcing the view that microbial processes play a large role in the bioavailability of both DP and PP reaching the watercourse.

#### Management and environmental factors influencing P mobilization

Management of buffer zones and the adjoining agricultural fields influences the potential for DP retention or mobilization (Table 3). One of two VFS in Sweden bordering an arable field, was found to be a source of DRP following 9 years of traditional cultivation practices (Uusi-Kämpä et al. 2000), likely due to large accumulation of PP. Implementing 3 years of grazing in the buffer to increase plant uptake, increased DRP retention resulting in the buffer returning to a modest DRP sink in the following 2 years under direct drill management. However, during grazing PP export increased and the buffer became a modest source of PP due to cattle grazing

and treading damage on the soil. This highlights the different responses of differing P forms to management and the complexity of developing effective CPs. As this study suggests, management of vegetation within buffer strips influences performance. Buffers where vegetation (grass) was regularly cut and removed showed a reduction in DRP load, while comparable buffers where vegetation was retained were found to be significant sources of DRP (Table 3; Uusi-Kämpä and Jauhiainen 2010). In addition to the removal of soil P through plant harvest and removal the contribution of plant residues at the soil surface in unmanaged riparian zones can make a large contribution to DRP loss especially in cold climates where much of the annual P loss occurs during snowmelt (Lui et al. 2013; Uusi-Kämpä and Jauhiainen 2010).

Transport pathway also influences the effectiveness of buffer zones. Most research has focused on the impact on surface runoff but the effect on subsurface losses remain uncertain (Table 3). Duchemin and Hogue (2009) investigated the impact of VFS on P loss in surface runoff and subsurface drainage from runoff plots under natural rainfall to Canadian manure amended pastures, 1 year after implementation. The VFS significantly reduced TP and DRP load to surface runoff compared to non-buffered controls but there was a large increase in TP and DRP load in drainage waters from 40 mg TP and 4.41 mg DRP per plot per year to 149–183 mg TP and 7.08–7.93 mg DRP per plot per year. At this site, the increase in subsurface P loss did not negate the large reduction in P loss to surface runoff due to the dominance of this pathway in transporting the majority of annual P loads and total P loss was reduced by 7 kg P Ha<sup>-1</sup>. However, where subsurface drainage is the dominant pathway buffer zones may not be effective CPs for P control. Noiji et al. (2013), compared P loss from pastures and fodder crop fields in the Netherlands bordered by buffer strips to unbuffered controls across a range of hydrological regimes. They found a significant reduction in TP and DRP load of 60 % for fields dominated by shallow subsurface flow, but no reduction in either parameter in fields dominated by deep subsurface flow or tile drains.

Environmental factors can exert control on mobilization of soil P stores. Wetlands, grassed waterways and riparian buffers prone to occasional flooding are all susceptible to changes in redox state. Redox conditions can have a large influence on P



mobilization through the reductive dissolution of Fe–P under anaerobic conditions and subsequent release of P (e.g., Surridge et al. 2007; Scalenghe et al. 2010). Additionally large pulses of P can be released from the microbial biomass following wet-drying cycles and freeze–thaw events (Blackwell et al. 2010). The increased accumulation of microbial biomass P in buffer soils compared to field soils (Table 4) will increase this risk.

#### Adoption considerations

There has been widespread adoption of riparian buffer zones, including grass/vegetative buffer strips and wetlands across Europe and the U.S. (Collentine et al. 2015; Osmond et al. 2012). While it should be remembered that riparian zones provide a wide range of ecosystem benefits, in terms of P mitigation, their impact is unclear (Table 3) and possibly overstated.

It is important to consider the appropriateness of CPs on a site by site basis, implementing a “right strategy, right place” principle. In the U.S., the Farm Service Agency (FSA) administers a voluntary conservation scheme called the Conservation Reserve Program (CRP) where farmers receive an annual payment to set aside land from agricultural production, and convert it to VFS, grass waterways and riparian buffers (FSA–USDA 2015 <http://www.fsa.usda.gov/programs-and-services/conservation-programs/conservation-reserve-program/index>). Sprague and Gronberg (2012) evaluated the relationship between total N and P export on 133 agricultural catchments across the U.S. and the area of land under CRP, which was roughly 8 % of total U.S. cropland in 2002. Modeling results showed that increased export of TP was significantly associated with an increase in area of land under CRP but that the association was stronger as the erodibility of soils, hence the proportion of PP transported, decreased.

Hydrology of the site can have a large influence on effectiveness of buffers. To effectively decrease P transport, run-off needs to flow evenly across the length of the buffer, i.e., via sheet flow (Hoffmann et al. 2009). However, during intense storms, runoff flow often converges into narrow flow paths, defined by site specific conditions, such as topography, soil type and physical characteristics, which may be influenced by land management (e.g., soil compaction). Surface runoff along narrow flow paths will

concentrate sediment and nutrient transport through a small area of the buffer zone (Owens et al. 2007) and may rapidly saturate the physical retention capacity for both sediment and DP. Field observations by Dillaha et al. (1989) indicated that farmers implemented VFS following federal cost-share programs with little consideration of site hydrology. Hence, the majority of filter strips implemented on 18 farms in Virginia for water quality improvement purposes were ineffective due to generation of concentrated flow paths. Consequently, in some cases careful design and maintenance of buffers at specific locations may be more effective than widespread implementation of a set buffer zone.

In summary, enrichment of buffer zone soils with labile forms of P, compared to the contributing agricultural fields, has been demonstrated, suggesting that soils in buffer zones can be a significant source of both inorganic and organic DP. Field studies have demonstrated that the effectiveness of buffer strips and wetlands decreases over time and that the risk of P release increases under certain management (Table 3). Such release of DP occurs for example, when protecting fields under conventional tillage and where plant material remains on the soil surface, and under certain environmental conditions, for example episodic flooding. This supports our second hypothesis that over time CPs that trap P within the landscape can become P sources instead of sinks. From the catchment monitoring trials shown in Table 2, no decrease in DRP loads were found for schemes where buffer strips or grassed wetlands were implemented and in two of the four studies there was a 37–92 % increase in DRP loads post implementation.

#### Conclusions

Current conservation schemes are often not sufficient to meet water quality targets. A review of field studies assessing the effectiveness of recommended CPs in the U.S. indicated that different CPs need to be adopted depending on the pollutant form and that many CPs designed to reduce sediment and PP transport can increase the export of DP. Furthermore CPs which act by trapping P within the landscape, such as buffers, wetlands and grassed waterways can accumulate P over time and become enriched with labile forms of P compared to adjacent field soils. This may result in



these P sinks transitioning into P sources. Consequently, in-stream water quality following CP implementation in catchment monitoring studies often shows reductions in PP export but no change, or even increases in DRP loading.

Of the current USDA-NCRS recommended CPs, nutrient management practices are the only strategies that consistently decrease DP losses (Table 1). However, while included in most catchment scale conservation schemes implementation of nutrient management plans meets farmer resistance. Furthermore, the fact that farmers are more reluctant to recognize the issue of dissolved nutrient losses compared to the easily visualized loss of particulates and studies, suggest that extensive education and outreach is required to improve nutrient management plan adoption (Osmond et al. 2015). Clearly, reductions in DP losses with current CPs are proving difficult. This has also been exacerbated by widespread adoption of CPs targeting erosion and PP which have been shown in some cases, to increase DP loss. For example conservation tillage and the widespread implementation of buffers and wetlands which accumulate P within the landscape.

Furthermore, due to the large timescales involved in decreasing soil P concentration through reduction or cessation of P inputs (Dodd et al. 2012; Meals et al. 2010), additional strategies to reduce DP losses from P enriched soils are urgently required. Possible strategies include vertical tillage and destratification of no-till soils to redistribute P accumulated at the soil surface (Kleinman et al. 2015), phytoextraction of P to accelerate the decline in soil P pools (Koopmans et al. 2004; van der Salm et al. 2009), especially in buffer zones and the use of Al or Fe industrial wastes as soil amendments to convert VFS soils acting as a DRP source into P sinks (Habibiandehkodi et al. 2015).

To improve the effectiveness, future conservation schemes require: (1) the selection of CPs based on the dominant form of P in runoff (DP or PP) and an understanding of possible tradeoffs between the two forms; (2) recognition that CPs designed to trap P within the landscape are at risk of becoming legacy P sources; (3) extensive education and outreach to ensure the widespread adoption of CPs targeting DP losses; and (4) inclusion of TDP in monitoring programs in addition to DRP as dissolved P<sub>o</sub> losses can be significant, especially from riparian zones.

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**PAYETTE RIVER SUBDIVISION NO. 2  
PROPERTY OWNER'S ASSOCIATION, INC.**



P.O. Box 1398

McCall, ID 83638

January 24, 2022

Ms. Cynda Herrick, AICP, CFM  
Valley County Planning & Zoning Administrator  
PO Box 1350  
Cascade, ID 83611

Subject: C.U.P. 21-45 Red Ridge Subdivision

Dear Ms. Herrick:

Payette River Subdivision #2 POA (PRS#2) appreciates the opportunity to comment on the proposed Red Ridge Subdivision, Conditional Use Permit 21-45. We were surprised to be made aware of McCall Associates LLC's late addition of the intent to utilize the West Mountain Water and Sewer (WMWS) system for 50 or possibly more lots within the proposal.

Mr. Dicken's statement that as CEO of WMWS he felt that the sewer system could handle up to 400 lots is suspect. Where is the data supporting this statement? Previous discussions with Mr. Dickens lead us to believe that the existing system is at or near capacity.

WMWS was initially designed, sized and constructed to accommodate PRS#2 and Blackhawk on the River (BTR) subdivisions. Our two subdivisions paid WMWS initial and ongoing costs passed on by the developers with the property price and hookup fees. While the initial design allowed for later expansions, the current two subdivisions are approaching build out and initial capacity design of the existing treatment facility. While the current facilities can be expanded, the costs are estimated to be in the millions. Any future expansion costs of these facilities rightfully should be the responsibility of the new developments.

Furthermore, DEQ Permit M-17-03 (Section 4.5 on page 14 of 32) states:  
Construction plans—Pursuant to Idaho Code 39-118, IDAPA 58.01.16 and IDAPA 58.01.17, detailed plans and specifications shall be submitted to the DEQ for review and approval PRIOR to construction, modification, or expansion of any wastewater treatment, storage, conveyance structures, ground water monitoring wells, or reuse facilities . . . Additional requirements are stated for flow measures, back flow prevention, and records retention.

We feel that CUP 21-45 approval should be denied until a full review and approval of the proposed expansion is completed by the DEQ. Additionally, we feel strongly that any expansion costs will be covered by the developer, McCall Associates LLC, and not the existing users of WMWS in BTR and PRS#2.

Thank you for your consideration.

Sincerely,

Chris Sours, Vice President  
Board of Directors

January 24,2022

Valley County Planning & Zoning  
C/O Ms. Cynda Herrick  
P.O. Box 1350  
Cascade, Idaho 83611

RE: CUP 21-35 Red Ridge Subdivisión

As a property owner in Payette River Subdivision #2, I am concerned about the applicant's intent to use the Western Mountain Water and Sewer System for an additional 50 or more sewer hook ups. The West Mountain Water and Sewer system was originally planned, approved and constructed to serve the two subdivision of Payette River Sub #2 and Blackhawk on the River. Initial construction and ongoing expenses costs were passed through to property owners in the two subdivision through their property cost and hookup fees. At this time the two subdivision are getting close to being fully built out, thus closely reaching the limits of the sewer system's design.

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While the current facility could be expanded, it is estimated that the costs could be in the millions. This cost should not be placed upon the shoulders of those utilizing the original system. Any cost of expanding and maintaining an expanded sewer system should be the sole responsibility of the developer.

The construction of the current sewer system was notorious for getting the cart ahead of the horse. Actions were taken prior to approval under the belief that it is easier to beg for forgiveness than to ask permission. I think it is important that a full review be made by DEQ and that its recommendations be closely followed if this subdivision is to be reviewed for approval.

Therefore, I am requesting that CUP 21-45 be denied until a full review and approval of the proposed expansion can be completed by DEQ. It is also important that should the expansion be approved, all expansion costs of the increased sewer capacity be covered by the developer and not placed upon the current users of the West Mountain Water and Sewer System.

Thank you for the opportunity to comment.

Judy L. Secrist

**From:** Jennifer Riso [REDACTED]  
**Sent:** Monday, January 24, 2022 3:36 PM  
**To:** Cynda Herrick <cherrick@co.valley.id.us>  
**Subject:** Red Ridge Subdivision

CAUTION: This email originated from outside of the organization. Do not click links or open attachments unless you recognize the sender and know the content is safe.

Dear Ms. Herrick,

We are homeowners of 275 Brook Drive in The Payette River Subdivision #2.

We are writing to express our deep concerns over the last minute addition to utilize WMWS for the proposed Red Ridge Subdivision.

We are specifically concerned about the expansion capabilities of WMWS as well as the costs associated with this proposed expansion. Any future expansion should be the full responsibility of the new developer.

We ask that CUP 21-45 be denied until full review & approval of the proposed expansion is completed by the DEQ.

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Thank you,

Jennifer & Joe Riso  
275 Brook Dr.  
McCall, ID 83638



**From:** Terry Aitable [mailto:taitable@qwest.net]  
**Sent:** Monday, January 24, 2022 3:56 PM  
**To:** Cynda Herrick <cherrick@co.valley.id.us>  
**Subject:** West Mt. Sewer and Water

As an owner in Payette River Subdivision #2, I am very concerned about the proposed development, Red Ridge . . . part of Blackhawk . . . and their desire to hook up to our waste system. Our system is nearly at capacity as it is ... and cannot possibly take on more affluent! Please keep me informed of this potential hazard!!

Terry Aitable  
119 moon Drive  
[REDACTED]

January 24, 2022

Ms. Cynda Herrick, AICP, CFM

Valley County Planning & Zoning Administrator

PO Box 1350

Cascade, ID 83611

Subject: C.U.P. 21-45 Red Ridge Subdivision

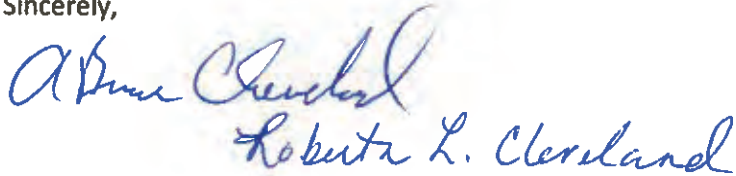
Dear Ms. Herrick

My name is A. Bruce Cleveland and my wife's name is Roberta L. Cleveland and we own lots 13 and 14 of Payette River Subdivision No. 2 (PRS#2) in Valley County. We are sending this letter in support of Chris Sours Vice President of PRS#2 letter (see attached) requesting the denial of CUP 21-45 Red Ridge Subdivision approval until a full review of expansion is completed by the DEQ. Additionally we agree that any expansion costs should be covered by the developer McCall Associates LLC.

We are retired and living on a fixed income, West Mountain Water and Sewer serves our home and any large billing expansion would cause a substantial hardship for us.

Thank you for your consideration.

Sincerely,

Handwritten signatures of A. Bruce Cleveland and Roberta L. Cleveland in blue ink. The signature of A. Bruce Cleveland is on the left, and the signature of Roberta L. Cleveland is on the right, partially overlapping the first signature.

A Bruce Cleveland & Roberta L Cleveland



**PAYETTE RIVER SUBDIVISION NO. 2  
PROPERTY OWNER'S ASSOCIATION, INC.**



P.O. Box 1398

McCall, ID 83638

January 24, 2022

Ms. Cynda Herrick, AICP, CFM  
Valley County Planning & Zoning Administrator  
PO Box 1350  
Cascade, ID 83611

Subject. C.U.P. 21-45 Red Ridge Subdivision

Dear Ms. Herrick:

Payette River Subdivision #2 POA (PRS#2) appreciates the opportunity to comment on the proposed Red Ridge Subdivision, Conditional Use Permit 21-45. We were surprised to be made aware of McCall Associates LLC's late addition of the intent to utilize the West Mountain Water and Sewer (WMWS) system for 50 or possibly more lots within the proposal.

Mr. Dicken's statement that as CEO of WMWS he felt that the sewer system could handle up to 400 lots is suspect. Where is the data supporting this statement? Previous discussions with Mr. Dickens lead us to believe that the existing system is at or near capacity.

WMWS was initially designed, sized and constructed to accommodate PRS#2 and Blackhawk on the River (BTR) subdivisions. Our two subdivisions paid WMWS initial and ongoing costs passed on by the developers with the property price and hookup fees. While the initial design allowed for later expansions, the current two subdivisions are approaching build out and initial capacity design of the existing treatment facility. While the current facilities can be expanded, the costs are estimated to be in the millions. Any future expansion costs of these facilities rightfully should be the responsibility of the new developments.

Furthermore, DEQ Permit M-17-03 (Section 4.5 on page 14 of 32) states:  
Construction plans—Pursuant to Idaho Code 39-118, IDAPA 58.01.16 and IDAPA 58.01.17, detailed plans and specifications shall be submitted to the DEQ for review and approval PRIOR to construction, modification, or expansion of any wastewater treatment, storage, conveyance structures, ground water monitoring wells, or reuse facilities . . . Additional requirements are stated for flow measures, back flow prevention, and records retention.

We feel that CUP 21-45 approval should be denied until a full review and approval of the proposed expansion is completed by the DEQ. Additionally, we feel strongly that any expansion costs will be covered by the developer, McCall Associates LLC, and not the existing users of WMWS in BTR and PRS#2.

Thank you for your consideration.

Sincerely,

Chris Sours, Vice President  
Board of Directors

January 25, 2022

Ms. Cynda Herrick, AICP, CFM  
Valley County Planning & Zoning Administrator  
P.O. Box 1350  
Cascade, ID 83611

Subject: C.U.P. 21-45 Red Ridge Subdivision

Dear Ms. Herrick

My wife and I are owners in Payette River Subdivision #2 and have read the letters from Chris Sours and Blackhawk concerned citizens. While much of the technical code and permit information is a bit Greek to us, we support the concern voiced in these letters and agree that West Mountain Water and Sewer should be responsible for maintaining the level of service to Blackhawk and Payette River Sub. #2 that they originally agreed to. Any expansion to the sewer system should, in our opinion, be a condition of any approval of addition dwelling units and should be incorporated in the developer's costs. We believe that most municipal sewer systems have these requirements placed upon developers when they seek to expand or add on to an existing sewer system.

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A layman's reading of these letters leads us to believe that Mr. Dickens is trying to pull a fast one and we, along with other homeowners, will support litigation if necessary, (although we hope it won't be) to protect our interests. Thank you for allowing us to voice our opinion.

Tim and Nadeane Rutledge  
Owners, Lots 30 & 31



January 26, 2022

Cynda Herrick  
Planning & Zoning Director  
Valley County  
Cascade, Idaho 83611

CUP 21-45 Red Ridge Preserve

Thank you to the Commissioners who saw that Red Ridge Preserve is not a viable development.

Since the January 10, 2022 meeting, residents close to the proximity of the proposed development have delved into the flagrant misinformation/ testimony given by Brian Dickens. Mr. Dickens arbitrarily changed his source of sewer and water from wells and septic to suggest that WMSW at Blackhawk on the River could accommodate the 135-lot Red Ridge residential subdivision.

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At present the DEQ Reuse Permit M-117-03 allows WMSW to accommodate 124 EDU hook-ups. The current Plant —a Class C recycled water reuse facility—is presently authorized to treat the 124 hookups. The users of the Permit are Blackhawk on the River and Payette Estates subdivision. The Original design was for a Class B treatment plant, but because of a lack of funds, the THEN developer built a lesser capacity treatment facility.

Mr. Dicken's at present has a DEQ "administratively-extended Permit. He had indicated in his correspondence he only intended to keep the "existing 124 EDU's. Any future development of Red Ridge Preserve needs to have environmental studies pertaining to the geology of the terrain for septic tanks, wells, erosion and the aquifer. No development of Red Ridge should be allowed without these Conditions of Approval.

We ask the Commission to deny CUP 21-45.  
Thank you for your consideration.

Sincerely  
Chris and Jack Oberti, Blackhawk on the River

From: Pat Bicknell [REDACTED]  
Sent: Wednesday, January 26, 2022 5:22 PM  
To: Cynda Herrick <cherrick@co.valley.id.us>  
Subject: Red River & WMWS

Re: Red River Subdivision

As a concerned resident of Payette River subdivision, we are requesting this request be denied until a full review and approval of the proposed expansion is completed by the Idaho DEQ.

From what we understand the West Mountain Water and Sewer (WMWS) is currently at capacity.

It makes no sense to rush this through without full and complete research to assist in making the right decision.

Please deny the request until further investigation is complete.

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Pat & Richard Bicknell  
Moonridge Dr  
McCall

January 27, 2022

PO Box 1251  
150 Current Drive  
McCall, ID 83638

Ms. Cynda Herrick  
P&Z Administrator  
Valley County, Idaho  
PO Box 1350  
Cascade, ID 83611

Subject: Concern over Issuance of CUP for Red Ridge Subdivision Development

Dear Ms. Herrick,

We are Michael and Sheila Forrest. We reside at 150 Current Drive, McCall, ID 83638. Our residence is located within Payette River Subdivision #2 and our sewage disposal is provided via West Mountain Water and Sewer (WMWS).

It is our understanding that the proposed planned development anticipates connecting to the sewage system owned by WMWS. It is also our understanding that the current sewage disposal system is at capacity and that an expansion of the capacity of the system would be required to provide for the needs of the new development. It is further our understanding that the capital cost of said expansion is in the range of \$10-15 million dollars.

We have no idea what the capital cost of the current sewage disposal system was when constructed but the cost of the expansion has to be a large multiple of that original cost. It also seems reasonable to assume that the current residents connected to the WMWS system would be expected to pay increased rates to account for a return on investment of the expansion and as a way to "soften the blow" to lot buyers in the new development. What that increase would be is anyone's guess, but we currently have no protections from anything WMWS wishes to do. After all, it is a privately owned system.

It is our opinion that this should be of interest to the Valley County P&Z Commission as well as the County Commission because we are certain that Payette River Subdivision #2 required a CUP prior to development and that as part of that CUP, the County required connections to WMWS as our only source of sewage disposal. Therefore, it is our opinion that Valley County has a fiduciary responsibility to make sure the existing rate payers are not taken advantage of by WMWS. If you folks approve this development without protecting existing WMWS rate payers from large rate increases, then you'll be violating that responsibility.

We do not know enough to comment on the merits of the development itself and whether or not it would be an asset to Valley County but we would offer that the development costs of the property alone given current construction costs coupled with the cost of the WMWS expansion will make the

parcels quite expensive and will naturally make the homes constructed on them very expensive as well. Is that good progress for our area given that there are many lots in Blackhawk subdivision and other subdivisions in and around the area that do not have homes on them or will it be just another example of the land in Valley County being available to only the very wealthy? It seems we have enough of that already. The market price on our home has doubled within two years. We could not afford to live here is we had to buy it at today's prices.

We trust that you'll do your jobs with integrity and proper diligence. Thank you for your consideration of our thoughts and opinion.

Sincerely yours,

Michael and Sheila Forrest

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Curt and Kim Meske  
45 Shooting Star Lane  
McCall, ID 83638

January 27, 2022

Valley County Planning and Zoning Commission  
219 N. Main Street  
PO Box 1350  
Cascade, ID 83611

Dear Commissioners:

We are writing in opposition to preliminary plat application of the McCall Associates, LLC ("Developer" or "Applicant") represented by Mr. Brian Dickens and Mr. Sima Muroff, Valley County application CUP 21-45 Red Ridge Preserve Subdivision Preliminary Plat ("Red Ridge"). As owners of lots 114 and 115 in Blackhawk on the River subdivision (BHOTR), which include our primary residence at 45 Shooting Star Lane, we are opposed to the approval of CUP 21-45 for the following reasons:

1. Risk to fisheries and water quality at Hait Reservoir (aka Blackhawk Lake).

The current proposal submitted indicates 135 home sites with individual septic systems surrounding Hait Reservoir/Blackhawk Lake, a trophy fishing lake in Valley County. If the commissioners approve CUP 21-45 in its current format, it will show that we have learned nothing from past problems with water quality in Valley County. The commissioners only need to recall the history of the Payette Lake Recreational Water and Sewer District beginning with the Clean Water act in 1969. We know from studies already done on Payette Lake, that septic systems surrounding lakes in Valley County are wrong. Septic systems and their nitrogenous discharge into surrounding land, which will eventually find its way into Hait Reservoir, will result in increased algae growth, water quality decrease and loss of fish habitat among other problems.

2. Lack of capacity for West Mountain Sewer and Water (WMSW):

During the January 13, 2022 Planning and Zoning Hearing, Mr. Dickens representing McCall Associates, LLC made several misleading statements to the commissioners

regarding the current capacity of WMSW for sewer hookup and ability to use water from the BHOTR community well system to support fire mitigation in the Red Ridge proposal. Several of our neighbors in BHOTR will be submitting letters of opposition in regards to CUP 21-45 with the facts about the current water production and sewer treatment capacity of WMSW, nonexistence of approved expansion plans for WMSW, and lack of planned or existing easements through BHOTR common area for proposed connections to the proposed subdivision, etc., so we will not reiterate those details in our letter. There will be more than enough detail in letters submitted by our neighbors in BHOTR regarding this issue, which will easily refute the misleading statements made by Mr. Dickens, and these details alone will be reason for the Commissioners to deny approval of CUP 21-45.

3. Unlikelihood of Applicant McCall Associates, LLC and Mr. Brian Dickens to actually follow CUP 21-45 conditions and stipulations if approval is granted.

The commissioners need to only review the CUP history, historic plat maps, existing build out of BHOTR and WMSW DEQ regulatory approval and maintenance history to see the disregard for rules and regulations which Mr. Dickens, as manager of Blackhawk, LLC, McCall Associates, LLC and WMSW, represents. Currently, Mr. Dickens disregard for rules and regulations leaves new owners and current residents of BHOTR at significant financial risk. If the Commissioners approve CUP 21-45, they will be spreading the risk of financial harm to current and future residents of Valley County.

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As an example of Mr. Dickens disregard for the previous CUP stipulations, I ask the commissioners to review Valley County CUP 05-03 from November 2020. Mr. Dickens, in submitting CUP 05-03 was successful in misleading Valley County Planning and Zoning and Valley County Commissioners by stating he was requesting a "reinstatement" for the plat for BHOTR that was approved by Valley County in 2006. Instead, the plat mistakenly approved by Valley County in 2020 was a completely new re plat of BHOTR which contained 11 new lots.

Unfortunately due to inadequate review by Planning and Zoning staff, Mr. Dickens was able to violate stipulation 12 from the 2013 BHOTR CUP 13-03 requiring "utilities including water and sewer be placed to each lot prior to final plat recordation, or shall be financially guaranteed" (implied guarantee granted by Blackhawk, LLC or McCall Associates, LLC who are party to CUP 13-03 and not WMSW). Subsequently, Mr. Dickens ability to mislead Valley County commissioners has left several new lot owners in BHOTR with financial liability of not having utilities installed on their property in BHOTR. From direct experience, we can bear witness to the fact Mr. Dickens is unable to or knowingly unwilling to follow through on this issue.

There are multiple other issues in how Mr. Dickens has previously mislead Valley County commissioners in the re plat of BHOTR in 2020, including exceeding WMSW capacity,

removal of pre planned easements within the subdivision, loss of common area access and even the need for Valley County to grant a variance to existing flood plain ordinances. The bottom line is that as representative of McCall Associates, LLC in presenting CUP 21-45, Mr. Dickens should not be trusted by Valley County Planning and Zoning commissioners in any capacity to follow through on any plans that the commissioners have for the guided development of Valley County.

We appreciate your time in review of our letter of opposition and ask that you deny CUP 21-45.

Kind Regards,

Curt and Kim Meske

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**From:** Linda Morris [REDACTED]  
**Sent:** Friday, January 28, 2022 4:26 PM  
**To:** Cynda Herrick <cherrick@co.valley.id.us>  
**Subject:** Red Ridge Preserve CUP 21-45

Dear Ms. Herrick and P&Z Commissioners:

Please consider the attached PDF letter in opposition to CUP21-45 following the January 13, 2022 meeting of the P&Z Commissioners. This letter is being submitted on behalf of 45 Blackhawk on the River (BOTR) lot/home owners rather than sending you 45 individual letters. You may also receive a few letters from BOTR homeowners and more lot owners from Payette Subdivision II. I trust this emailed letter will be forwarded to each of the five (5) P&Z Commissioners. Under separate cover, I will be sending you a hard copy of this letter to your office in Cascade, Idaho.

Respectfully submitted,  
Linda Morris  
[REDACTED]

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January 28, 2022

Dear P&Z Commissioners:

On behalf of 45 Blackhawk River (BOTR) property owners, we would like to voice our opposition for CUP 21-45: RedRidge Preserve Subdivision. We are submitting our concerns after listening to the January 13 P&Z meeting and learning of the plan to link the Red Ridge Subdivision into the West Mountain Water & Sewer (WMWS) system located within the boundaries of the Blackhawk River subdivision. We have not only watched the January 13 meeting, but also we have also reviewed the CUP 21-45 application materials, the DEQ Permit (M-117-03), and contacted the DEQ with further questions about WMWS. You will be receiving letters from other concerned homeowners who have received more information from DEQ.

It may be noted that only one person from Blackhawk River sent a letter of concern to the P&Z before the January 13 meeting. The neglect was not intentional. Rather, many of the 120 or so lot owners never received notice about the January 13 hearing. The BOTR Board did not send a notice to owners because even they didn't know Mr. Dickens had submitted CUP 21-45 in December 2021. For your information, the majority BOTR owners (according to Mr. Dickens there were 68 lots sold in 2020-2021) do not live in McCall or Valley County. Lot owners did not received a notice from the P&Z and many of them would not have seen the notice posted in the McCall Star News. In the future, we request better communication so every owner is aware of proposed changes to Blackhawk River subdivision (BOTR). And, please include lot owners in Payette Subdivision II regarding any future public meetings about WMWS.

Please know that BOTR owners are especially appreciative of the two commissioners who noted the discrepancy between the submitted application and the statements made by the Independent Manager/Applicant, Brian Dickens, during the January 13 P&Z meeting. We are also pleased the P&Z Commission voted to continue discussion on CUP 21-45 and to request more information on the water, sewer, and soil concerns expressed by our neighbors in Blackhawk Lake and Blackhawk Ranch. It appears that after hearing their concerns, Mr. Dickens made an on-the-spot decision to use WMWS without informing BOTR owners and its Board of Directors. Integrating a new subdivision into WMWS has a tremendous impact on the two subdivisions it presently serves, i.e., the 144-lot Blackhawk River Subdivision and the 88-lot Payette Subdivision II. Payette Subdivision II owners, also not aware of CUP 21-45, have now be notified and will be actively engaged at the February 10 P&Z meeting.

At the January 13 meeting, Mr. Dickens also stated the proposed the water and sewer infrastructure could cross West Mountain Road and utilize Blackhawk River's common areas for access to the lagoons located on Shooting Star Street and use Blackhawk River's water wells. Clearly, these statements were intended to sway the vote of the P&Z commissioners. But, such a statement also brings up land usage issues and water rights since Mr. Dickens deeded all common areas to BOTR in October 2020.

Another concern for Blackhawk River, Lake, and Ranch owners was the presence of Mr. Sima Muroff at the P&Z meeting. Given the past history of the Blackhawk enterprises, red flags were immediately raised. As you may know, Mr. Sima Muroff, the former owner/developer, was fined about \$7-8M for his fraudulent activities in misusing investment funds for his personal use during the development phases for Blackhawk Lake, Ranch and River. The SEC has been involved in this legal case since 2012 and in 2016 appointed Mr. Dickens as an Independent Manager although he was involved with Mr. Muroff in attracting investors in the Blackhawk development under the EB-5 program. Over the past 5-6 years, Blackhawk River COA has had a stormy relationship with Mr. Dickens as he constantly touts he has the voting power to overrule the Blackhawk River owners (who are also property investors) rather trying to work with Blackhawk River to become a self-governing HOA. His authoritative leadership is based on Blackhawk River's CC&Rs that are written to favor the developer until 90% of all lots are sold. When the 2020 lot-sales was reaching the 90% threshold (~128 lots of 144) Mr. Dickens pulled the remaining lots off the market. If Red Ridge Preserve becomes a subdivision, BOTR owners caution that no subdivision should follow the CC&Rs of BOTR. We have endured the last 10-12 years of legal problems, irresponsible leadership, and a stranglehold on becoming a fully functioning HOA.

On or about February 2021, the attorney, representing the initial investors, asked the federal court to dispose of the remaining Blackhawk assets so they could recoup what is left and end the 11-year legal process. That is why an auction is being scheduled for May 2022, although it was initially set for October 2021. The Blackhawk assets include the remaining 18-20 unsold lots in Blackhawk River, the 2600+ acres in Red Ridge (inclusive of the proposed 1600 acres in CUP 21-45), and the privately owned WMWS utility. And, it should be noted that the 2006 BOTR CC&Rs state that WMWS must be turned over to a 3rd party in 2025. For all of Blackhawk River owners, we had hoped the auction would terminate the stronghold on our subdivision and we could revise our CC&Rs and set our own destiny. But, when Mr. Muroff emerged again at the January 13 meeting and his name remains listed as the primary administrator for WMWS on the DEQ Permit M-117-03, alarms were set off again. Such information has now been forwarded to the attorney representing the initial investors regarding McCall Associates actions and the proposed CUP 21-45 application for Red Ridge Preserve.

Here are some additional facts/information the P&Z must consider:

- 1) The DEQ Permit M-117-03 issued August 19, 2015 expired as of August 11, 2020 (see [www2.deq.idaho.gov](http://www2.deq.idaho.gov)) and the 2015 permit states there are 124 EDUs (equivalent dwelling units) for WMWS. The Lodge, a 10,000 square foot building with a swimming pool, showers, sauna, steam room, toilets, etc. is not an EDU per DEQ's definition. The Lodge is located on Lot 99-100. There are 12 lots (Lots 109-120) that have a 4-condo complex totaling 12 units. These lots may/may not be a separate PUD from BOTR lots, but all lots are using WMWS services. DEQ needs consider whether Lots 99-100 and Lots 109-120 meet the standards of an EDU. You will note on page 12 of 32 of DEQ Permit M-117-03, the Compliance Activity (CA) and the Completion Dates. CA 117-08 specifies 124 EDUs as the permitted units; CA 117-10 specifies the Renewal Permit Application must be filed 6 months prior to the expiration date of August 11, 2020. We have been informed by the DEQ that a temporary permit is under consideration for WMWS since the deadline for renewal was not met. The Blackhawk River owners would like to know the status of this temporary permit and who is listed as the official administrator of WMWS—Mr. Dickens or Mr. Muroff?
- 2) WMWS Capacity—At the January 13 P&Z meeting, Mr. Dickens stated that WMWS has current water/sewer capacity is for 250 lots (not the 124 EDUs on Permit M-117-03). Later in the meeting he mentioned a capacity of 450 lots if designed for a Class A treatment plant. I think Mr. Dickens is referring to the original Blackhawk development plans (under Mr. Muroff's ownership) for building a Class B-system that would have accommodated 250 users. The DEQ has confirmed that the current system was approved as a Class C system to accommodate 124 EDUs, not the 250 for a Class B system. For any future expansion or modification, the question is whether there is enough acreage on the WMWS parcel to add more lagoons and expand the Class C system to 250 lots? Is there enough acreage on the WMWS parcel to upgrade to a Class A or B system? These are questions the DEQ must answer. If there is insufficient acreage, then WMWS does not even have the capacity to meet its current lot owners' needs as explained below:
  - Mr. Dickens referred to the 2020 re-plat of Blackhawk River. This 2020 plat shows 144 lots to be supported by WMWS. Lot 99-100 is the Lodge, Lots 109-120 are condo units. Lots W1 and W2 are WMWS well (RP005760030W10 and RP005760030W20); Lots LS1 and LS2 are the WMWS lift stations (RP00576003LS10 and RP00588006LS20). Mr. Dickens has repeatedly stated to some of us that Lot 144 (RP006680290000), a 11-acre parcel at the end of Moonflower Lane, could be subdivided into 8 more lots potentially making BOTR into a 152-lot subdivision. Obviously, such action is intended to make the threshold of 90% of sold lots more difficult to reach, but it also results in more BOTR lot users for WMWS services.

Then consider that Payette Subdivision II (across the Payette River from Moonflower Lane) is connected to WMWS for sewer only and that subdivision includes 88 lots of which 68 are presently connected to WMWS per the HOA president. Do the math—144 lots (including the Lodge and 12 condo units); 8 potential lots by subdividing Lot 144, 88 lots in Payette Subdivision II and the proposed 50 lots on the northern end of RedRidge Preserve Subdivision. And, the P&Z must consider the acreage on the WMWS parcels to expand the existing Class C system or change it to a Class B system. Currently, WMWS currently serves about 98 customers between the 2 subdivisions (Blackhawk and Payette Subdivision II) so that leaves 26 EDUs remaining ( $124 - 98 = 26$ ) in these 2 subdivisions totaling 232 current customers (144 BOTR plus 88 Payette Sub II). The 232 customer base excludes the 8 additional lot units to be subdivided on Lot 144, but does include the Lodge and the condo lots.

3. Impact on Blackhawk River Subdivision: Mr. Dickens' CUP 21-45 application [see Item 16 (on page 11 of 12)] states there will be "no impact on adjacent subdivisions, products, or services." On item 18 (same page) he states bonds will be issued for construction costs of Red Ridge Preserve but there is no mention of WMWS.

It should also be noted that DEQ Permit M-17-03 (Section 4.5 on page 14 of 32) states: Construction plans—Pursuant to Idaho Code 39-118, IDAPA 58.01.16 and IDAPA 58.01.17, detailed plans and specifications shall be submitted to the DEQ for review and approval PRIOR to construction, modification, or expansion of any wastewater treatment, storage, conveyance structures, ground water monitoring wells, or reuse facilities... Additional requirements in Section 4.5 are stated for flow measures, back flow prevention, and records retention. Impact on Blackhawk River Subdivision.

The 45 Blackhawk Concerned Owners emphasize that connecting 50 more units to WMWS will have a DIRECT IMPACT on BOTR lot owners as substantiated in the following paragraphs:

- a. During the hearing, Mr. Dickens suggested that the northernly end of Red Ridge Preserve Subdivision could be connected to WMWS by coming across West Mountain Road and through the common areas of Blackhawk River to reach the lagoons located on Shooting Star. He also proposed the use of Blackhawk River's water well. It should be noted that in October 2020, Mr. Dickens transferred the deeds to all common areas to the Blackhawk River Community Owners' Association (COA). Both suggestions bring up the legal rights to use the BOTR's common areas and its water rights.
- b. According to reliable sources, a conservative cost estimate to double the capacity (from 124 EDUs to the current customer base of 232 ) to serve existing lot owners is about \$10-\$15M. It would be even more costly to change from a Class C to a Class B system or to add an additional 50 lots in the Red Ridge subdivision. For the record,



we note that in our CC&Rs, Section 9.II: Transfer of Water Systems states: Modifications to the water system facilities for the purposes of providing water service to nearby developments shall be made at the sole expense of the Grantor. And the 2006 CC&Rs state that WMWS must be transferred to a 3rd party in 2025.

- c. The DEQ must also thoroughly review the existing Class C system for compliance issues and ensure users and the P&Z about any potential failures with increased usage. A few owners have made inquiries to the DEQ, and it appears that regular reports have been submitted on time and in compliance to date. However, about 3 years ago, there were problems with the chlorination system and these repair costs were passed on to the current homeowners via an increase in their water/sewer monthly fees. Now with an estimated \$10-15M cost and no mention of a bond for WMWS, the lot owners are worried about the potential increase in usage rates managed by this private utility.
- d. While it might appear the current Class C system is in compliance it should be pointed out that about 2 years ago there was a breach (double redundancy failure) at the end of Evening Star Street where raw sewage was seeping from the drain. The emergency system was not operating properly. Luckily, a homeowner called the WMWS manager who immediately repaired the problem before any seepage reached the nearby Payette River. Clearly, this is a concern to the Idaho Fish and Game Department who submitted a letter to the P&Z at the January 13 meeting.
- e. There are acreage requirements for sewer lagoons to meet DEQ standards, especially the Class C system currently in place. Even if additional lagoons could be built on the WMWS parcel, there may be insufficient acreage to spray the waste effluent. The Blackhawk owners request the DEQ to inspect the current Class system for needed repair & maintenance as well as acreage needed for expansion purposes.
- f. The existing Class C waste system is permitted to spray waste effluent onto the WMWS parcel. During the summer months, the stench from the spray can be smelled to the down-wind homes on Shooting Star and across the empty lots to residents on Moonflower Lane, a street below Shooting Star. The air quality is becoming a major concern to homeowners. Adding more lagoons to accommodate more homeowners and spraying the waste effluent onto the small forested land parcel needs a thorough environmental assessment. Again, this impacts homeowners environmentally and also devalues their homes and lots.

In conclusion, the 45 Blackhawk River Concerned Owners greatly appreciate the two commissioners, who questioned the initial application and who requested a continuance before voting on CUP 21-45. In the February 10 hearing, the P&Z will definitely hear more concerns from the lot owners in Payette Subdivision II, Blackhawk Lake, and Blackhawk Ranch. Also, the Boise attorney representing the initial investors has been alerted to the upcoming May 2022 auction, the 2015 DEQ permit listing the Mr. Muroff

as the official administrator, and the proposed Red Ridge plan (CUP 21-45) to integrate 50 lots into WMWS resources. Given our findings and concerns, the Blackhawk River owners ask that the P&Z Commissioners to:

- Deny CUP 21-45 until the above issues are addressed and until the ownership status of WMWS is determined following the May 2022 auction.
- Address the infrastructure costs and DEQ engineering requirements to meet the current water and sewer standards for existing 232 owners in Blackhawk River and Payette Subdivision II. These subdivisions have priority status before adding 50 more units from Red Ridge Preserve.

Respectfully submitted,

Blackhawk River Concerned Owners

Signed by Linda Morris, Blackhawk homeowner and past COA Board Member

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January 28,2022

Cynda Herrick, P&Z Administrator  
PO Box 1350  
Cascade, Idaho 83611

Subject: C.U.P. 21-45 Red River Subdivision

Valley County P&Z:

We are writing in opposition to the proposed Red Ridge Subdivision, C.U.P 21-45. After reading the Star News article in the January 20<sup>th</sup> edition, and then receiving additional information from our Payette River Subdivision #2 POA (PRS#2), we find that there needs to be much greater attention paid to the sewer system regulations. DEQ has to be involved in approving this BEFORE any further development can occur. The current permit expired in 2020. We currently pay \$54 per month for our sewer, which is already expensive enough. Do the right thing and deny this application. If the developer (McCall Associates LLC) wants to continue with this development, the cost of the expansion should be in his court, and not be placed on the existing users.

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Be proactive on this subject and not reactive; which has been the case so many times. We as a county (and state) need to ensure that projects like this are handled properly BEFORE approval and not after.

Thank you.

Darcy & Travis Reese – full time residents in PRS#2

361 Moon Drive

McCall, ID 83638

**From:** Kelly & Marji Guy [REDACTED]  
**Sent:** Friday, January 28, 2022 2:05 PM  
**To:** Cynda Herrick <cherrick@co.valley.id.us>  
**Subject:** CUP 21-45 RedRidge Preserve Subdivision

Director Herrick,

We are residents of Blackhawk on the River and have several specific concerns that we would like the P&Z Commission to consider relating to CUP 21-45 RedRidge Preserve Subdivision during the continuation of the hearing scheduled for February 10th, 2022.

1) As a resident of a nearby subdivision, at no time prior to the initial hearing did we receive any mailed notification of the permit application or scheduled P&Z hearing. We learned of the hearing from the notice in the paper which specifically detailed individual wells and septic systems. The changes to water and waste disposal as suggested by the developer in the January 13, 2022 hearing should trigger a new notification period as they are material changes to the original permit application.

2) The West Mountain Sewer and Water facility that is referenced by the developer in the hearing is currently operating under an expired permit from Idaho DEQ (expiration date 8/19/2020). The expired permit authorizes connection of a maximum of 124 EDU's to WMSW's facility. During the hearing, the developer stated that the facility is currently permitted for 250 homes and is designed for 450 homes. We would request that the P&Z Commission take this information into account and seek clarification and appropriate permitting from the developer prior to approval.

3) During the hearing we heard reference to many submitted concerns regarding the effect of this development on traffic on West Mountain Road. We share these concerns as they relate to safety of cyclists, pedestrians, and motorists that use West Mountain Road, the amount of construction traffic and the resulting wear and tear on the road.

4) In the application on page 37 there is a reference in Phase 2 to Perimeter Fencing. We would request that the P&Z Commission ask for more information on the developer's intent here as any fencing outside of individual home units could potentially create problems for the wildlife in the area and should be limited in scope.

Our thanks to the Planning and Zoning Commission and Staff for continuing to work at the challenging task of managing the growth in Valley County while balancing the rights of both current residents and landholder/developers.

Regards,

Kelly Guy  
22 Arrowgrass Way  
Blackhawk on the River  
McCall, Idaho 83638



February 2, 2022

Planning and Zoning Commissioners  
Valley County  
219 North Main Street  
Cascade, ID 83611

RE: C.U.P. 21-45 Red Ridge Preserve Subdivision

Commissioners,

It is time to put an end to the charade brought forward by McCall Associates, LLC. It is becoming clear that they have no intent to execute this planned development. This C.U.P. request and all of their rhetoric is simply a ploy to inflate the perceived value of this property and other assets that will be auctioned off in the spring.

Why is this developer being allowed to waste the time of the Planning and Zoning Commission, the other Blackhawk communities, and individual property owners that only want a legitimate plan to discuss. It is time to stop allowing this investor to misrepresent his intentions.

I ask you to stop the waste of resources, stop the misrepresentation, stop this dishonesty now. Please deny C.U.P. 21-45.

Best regards,

Walt Sledzieski  
Blackhawk Lake Estates

**From:** Dan Barnes. [REDACTED]  
**Sent:** Wednesday, February 2, 2022 4:15 PM  
**To:** Cynda Herrick <cherrick@co.valley.id.us>  
**Subject:** C.U.P. 21-45 Red Ridge Subdivision / Sewer Issues

I received copies of two letters written on behalf of Blackhawk River and Payette Subdivision II property owners. I am alarmed at the suggestion that the existing sewer system may not be adequate to service these two associations, much less the additional framework needed to support the Red Ridge Subdivision.

The letter written by the Blackhawk River owners warns of a 'potential environmental disaster' if certain steps are not taken to ensure the integrity of the West Mountain Sewer and Water system.

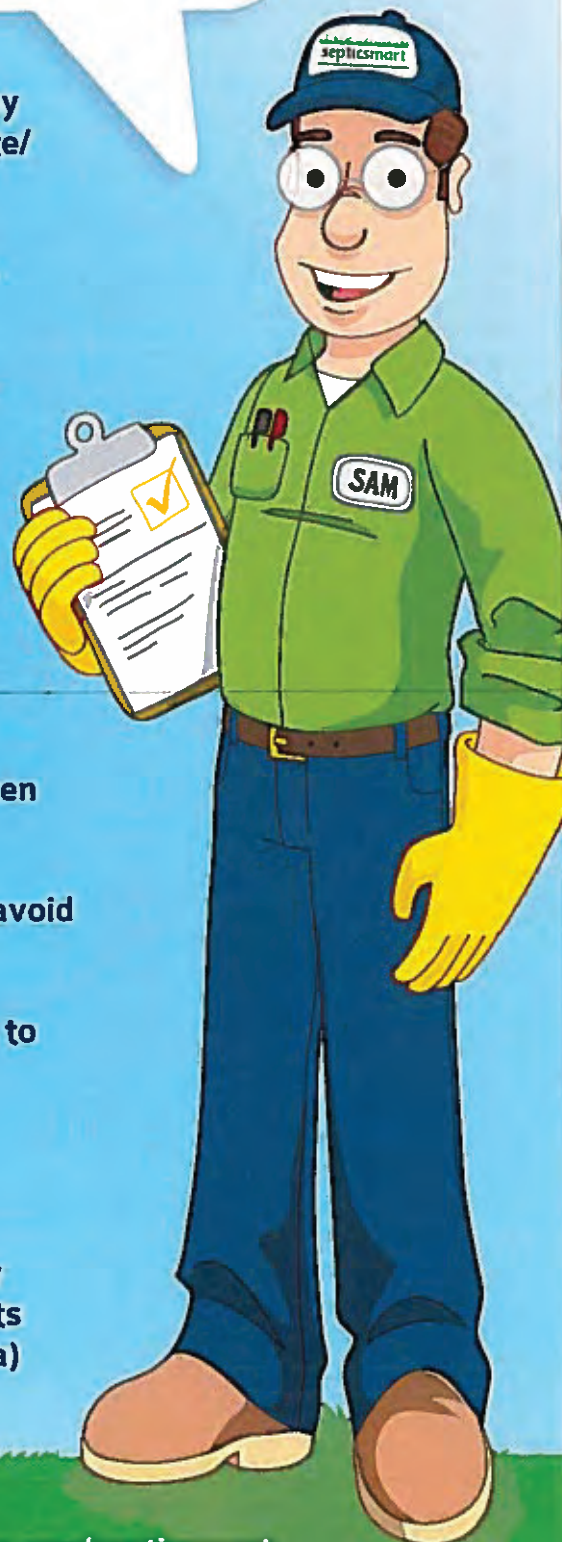
I urge you to delay or deny approval on the Red Ridge proposal until a full review of WMWS has been completed by the DEQ.

Best regards,  
Daniel R Barnes  
Consolata Viglietti  
295-Brook Dr.  
Payette Subdivision II

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# Top 10 Ways to Be a Good Septic Owner

- ✓ Have your system inspected every three years by a qualified professional or according to your state/local health department's recommendations
- ✓ Have your septic tank pumped, when necessary, generally every three to five years
- ✓ Avoid pouring harsh products (e.g., oils, grease, chemicals, paint, medications) down the drain
- ✓ Discard non-degradable products in the trash (e.g., floss, disposable wipes, cat litter) instead of flushing them
- ✓ Keep cars and heavy vehicles parked away from the drainfield and tank
- ✓ Follow the system manufacturer's directions when using septic tank cleaners and additives
- ✓ Repair leaks and use water efficient fixtures to avoid overloading the system
- ✓ Maintain plants and vegetation near the system to ensure roots do not block drains
- ✓ Use soaps and detergents that are low-suds, biodegradable, and low- or phosphate-free
- ✓ Prevent system freezing during cold weather by inspecting and insulating vulnerable system parts (e.g., the inspection pipe and soil treatment area)







# **A Homeowner's Guide to Septic Systems**



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**Idaho Department of Environmental Quality  
1410 N. Hilton  
Boise, ID 83706**

**January 2001**

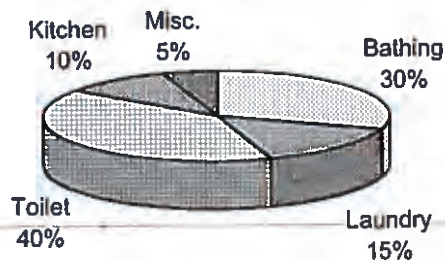


**D**o you have a home septic system? As an Idaho resident, there is a good chance you do—thirty-six percent of Idaho's homes, or about 210,000 residences, use septic systems to treat their sewage. These systems discharge more than 53 million gallons of wastewater into Idaho's soils annually, and this figure grows each year. In 1999, Idaho's seven health districts issued over 6,100 permits for new septic systems.

Septic systems dispose of household sewage, or wastewater, generated from toilet use, bathing, laundry, and kitchen and cleaning activities. Because septic systems are underground and seldom require daily care, many homeowners rarely think about routine operations and maintenance. However, if a septic system is not properly designed, located, constructed, and maintained, groundwater may become contaminated.

### Household Wastewater

Households that are not served by public sewers depend on septic tank systems to treat and dispose of wastewater. Household wastewater carries with it all wastes that go down the drains in our homes, including human waste, dirt, food, toilet paper, soap, detergents, and cleaning products. It contains dissolved nutrients, household chemicals, grease, oil, microorganisms (including some that cause disease), and solid particles. If not properly treated by your septic system, chemicals and microorganisms in wastewater can travel through the soil to groundwater and pose a health hazard.



The average person uses between 50 and 75 gallons of water per day; mostly in the bathroom. Reducing your water use will help your septic system to work more efficiently.

### Your Septic System

A conventional septic system has three working parts: a septic tank, a drainfield, and surrounding soil.

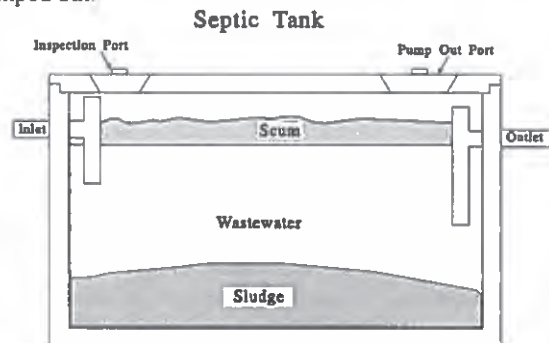
#### Septic Tank

Septic tanks can be made of concrete, fiberglass, or plastic and must be approved by the state. Minimum sizes of tanks have been established for residences based on the number of bedrooms in the dwelling. In Idaho, a 1,000-gallon septic tank is required for homes with three or four bedrooms. Larger tanks are required for larger homes. Local district health departments issue permits for septic systems and specify the minimum size tank. Some systems installed before the current rules and regulations may have smaller septic tanks.

A septic tank has three main functions:

- to remove as many solids as possible from household wastewater before sending the liquid, called “effluent,” to a drainfield;
- to decompose solids in the tank; and
- to store solids that do not decompose.

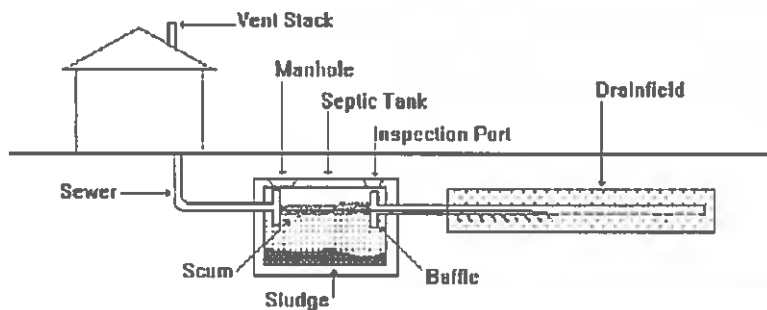
When raw wastewater enters the tank, heavy solids sink to the bottom of the tank as sludge. Light solids, such as grease and paper, float to the surface as scum. During the wastewater storage period, bacteria digest organic material in the wastewater. During this process, the solid material is reduced in volume and composition. Solids that do not decompose accumulate in the tank and eventually must be pumped out.



Tees, or baffles, are provided at the tank's inlet and outlet pipes. The inlet tee slows the incoming wastes and reduces disturbance of the settled sludge. The outlet tee keeps the solids and scum in the tank. As new wastewater enters the tank through the inlet tee, an equal amount of wastewater is pushed out of the tank through the outlet tee. The effluent that leaves the tank has been partially treated but still contains disease-causing bacteria and other pollutants.

### **Drainfield**

Each time raw wastewater enters the tank it forces an equal amount of effluent into a drainfield. A standard drainfield is composed of a series of perforated pipes buried in gravel-filled trenches in the soil. The effluent seeps out of the perforated pipes and percolates through the gravel to the soil.



### **Soil**

The soil below the drainfield provides the final treatment and disposal of the septic tank effluent. After the effluent has passed into the soil, most of it percolates downward and outward, eventually entering the groundwater. Soils are critical to the treatment of septic tank wastewater.

A system that is not functioning properly will release nutrient-rich and bacterial-laden wastewater into the groundwater and/or surface water. These contaminated waters pose a significant public health threat to people that come into contact with them. Wastewater that moves with groundwater can transport bacteria considerable distances. This can result in a threat to public health and adversely affect the quality of ground and surface waters.

## **Caring for Your Septic System**

### **Installing Your System**

In order to have a septic system installed on your property, you must first obtain a permit. Permit applications are available from your local district health department. Next, you must have a site evaluation performed. Make arrangements for this with your district health department and with a licensed septic system installer. Note that not all property is suitable for septic systems, so some permits may be denied. It is recommended that you have a site evaluation performed before you purchase property. Finally, have your system installed by a licensed installer and inspected by your local health district. Provide regular, preventative, maintenance to keep your system running smoothly.

### **Inspecting Your System**

When too much sludge and scum are allowed to accumulate in your tank, the incoming sewage will not have enough time in the septic tank for solids to settle. Solids may flow to the drainfield and clog the pipes, causing the sewage to overflow to the ground surface, where it exposes humans and animals to disease-causing organisms. To prevent this from happening, it is very important to inspect your tank regularly and have it serviced when needed. All tanks have accessible manholes for inspecting and pumping. Some excavation work may be needed to uncover the manhole.

Properly designed tanks should have enough capacity for three to eight years of use before needing service. This is dependent upon the amount of wastewater generated. It is recommended that an average family of four have its septic tank pumped out every three to five years. Don't wait for signs of system failure to have your tank pumped. Your tank should be checked annually to measure sludge and scum levels. A licensed septic tank pumper can provide a septic tank inspection and recommend when the tank should be pumped. A tank inspection should include measuring the depth of scum and sludge and inspecting the tees in the septic tank.

If you do the inspection yourself, it is important to understand that septic tanks always appear full because both the inlet and the outlet are at the top of the tank. What you will need to know is how much of the tank's volume is being taken up by scum and sludge. When sludge and scum take up more than 35 percent of the tank volume, these solids need to be removed by pumping. A pole wrapped in a coarse weave cloth can be used to check the sludge depth. An extension on the pole can be used to measure the scum depth. Record these measurements as part of your pumping records. To check the tees, uncover the inspection ports.

Never allow anyone to enter your septic tank. Dangerous gases and the lack of oxygen can kill in minutes.

While it is impractical to inspect the pipes in your drainfield, it is important to watch for drainfield failure or overuse. See "Warning Signs of System Failure" in this booklet for information.

### **Maintaining Your System**

Pumping your septic tank every three years (or as determined by your inspections) will remove accumulations of solids, help keep the drainfield from becoming clogged, and help prevent you from experiencing sewage backups or septic system failure. An accumulation of sludge exceeding 35% of the total water depth in the septic tank could cause solids to enter the drainfield and clog the system. Hire a licensed septic tank pumper to pump your tank for you.

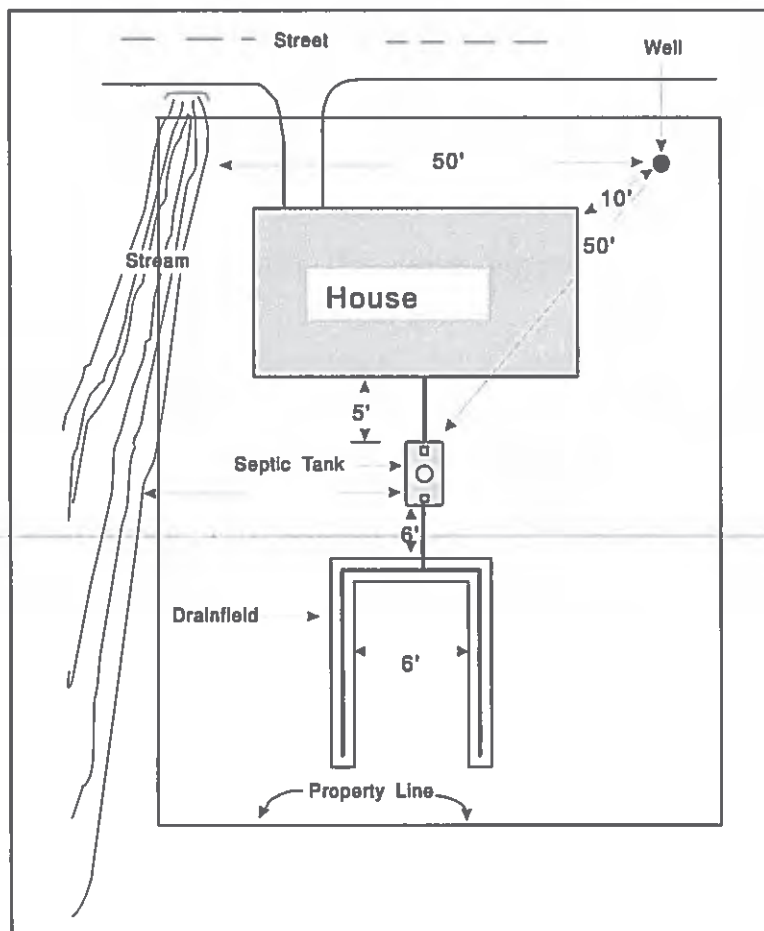
### **Mapping Your System**

In order to take proper care of your septic system, you must know the location of the septic tank and drainfield. The location of your septic tank can be determined from plot plans, septic system inspection records, architectural or landscape drawings, or from observations of the house plumbing. If you do not have access to drawings, find where the sewer pipe leaves your house. Some installers mark the location where the waste pipe comes out of the house with an "S" on the foundation. You may want to do this as well. Probe in the ground 10 to 15 feet directly out from the location where the pipe leaves your house to find your tank.



Once the septic tank has been located, make several plot plan diagrams (with measurements) that include a rough sketch of your house, septic tank cover, drainfield area, well, and any other permanent reference points (such as trees or large rocks) and place them with your important papers. You'll find a sample system diagram on the next page, and a place to draw your own inside the front cover of this booklet. You may also want to hang a diagram in your garage and provide one to your local district health office.

Maintain a permanent record of any septic system maintenance, repair, sludge and scum levels, pumping, drainfield condition, household backups, and operations notes.



**Create a septic system diagram, similar to this one, for your system.**

## **Warning Signs of System Failure**

While proper use, inspections, and maintenance should prevent most septic tank problems, it is still important to be aware of changes in your septic system and to act immediately if you suspect a system failure. There are many signs of septic system failure:

- surfacing sewage or wet spots in the drainfield area;
- plumbing or septic tank backups;
- slow draining fixtures;
- gurgling sounds in the plumbing system;
- sewage odors in the house or yard (note that the house plumbing vent on the roof will emit sewage odors and this is normal); and
- tests showing the presence of bacteria in well water.

If you notice any of these signs, or if you suspect your septic tank system may be having problems, contact a licensed septic system professional or your local district health agency for assistance.

## **Septic System Dos and Don'ts**

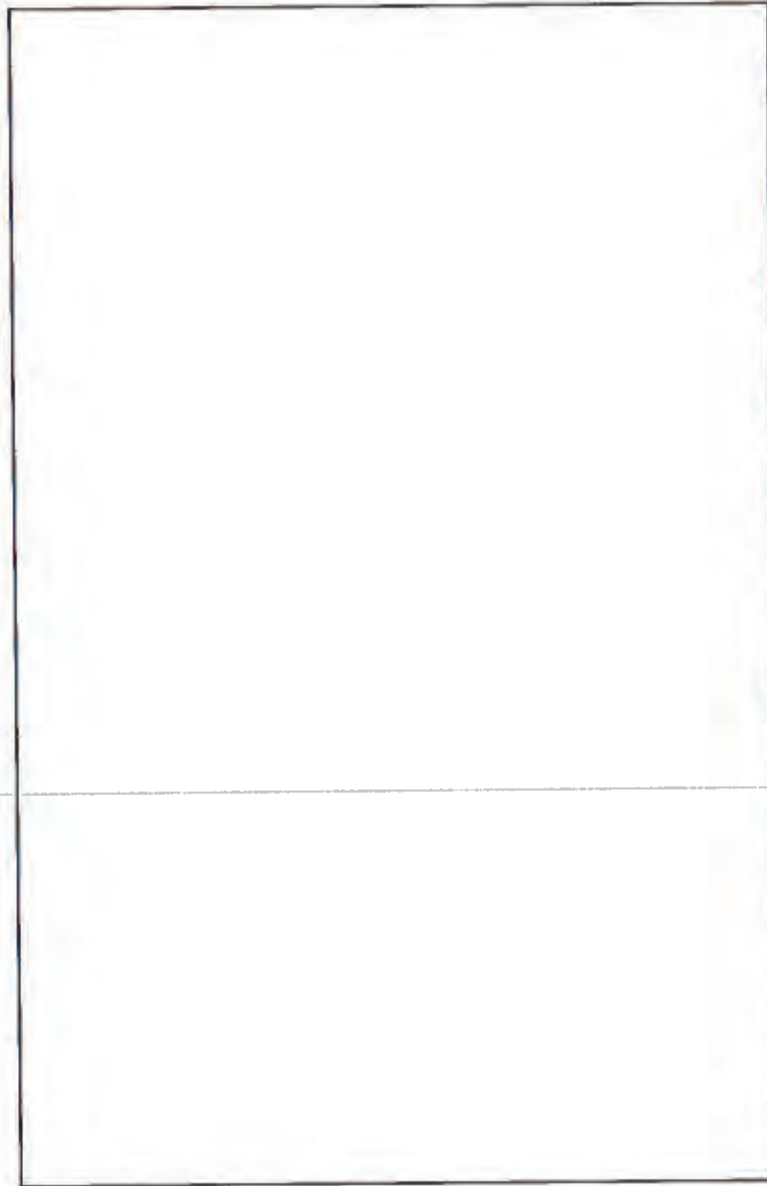
Proper operation of a septic system can prevent costly repairs or replacement. Observing the following guidelines will help to keep your system running efficiently.

### **Do**

- ...practice water conservation. The more wastewater you produce, the more wastewater your system must treat and dispose. By reducing and balancing your use, you can extend the life of your system and avoid costly repairs.
  - Use water saving devices such as low flow showerheads.
  - Repair leaky faucets and plumbing fixtures immediately.
  - Reduce toilet reservoir volume or flow.
  - Take short showers.
  - Take baths with a partially filled tub.
  - Wash only full loads of dishes and laundry.
  - Shut off the water while shaving or brushing your teeth.
  - Balance your water use (e.g., avoid washing several loads of laundry in one day).
- ...keep accurate records. Know where your septic tank is, keep a diagram of its location using the space provided in this booklet, and keep a record of system maintenance.
- ...inspect your system annually. Check the sludge and scum levels inside the tank and periodically check the drainfield for odors, wet spots, or surfacing sewage.
- ...pump your system routinely. Pumping your septic tank is probably the single most important thing you can do to protect your system.
- ...keep all runoff away from your system. Water from roofs and driveways should be diverted away from the septic tank and drainfield area. Soil over your system should be mounded slightly to encourage runoff.
- ...protect your system from damage. Keep vehicles and livestock off your drainfield. The pressure can compact the soil or damage the pipes. Before you dig for any reason, check the location of your system and drainfield area.
- ...landscape your system properly. Plant grass over the drainfield area. Don't plant trees or shrubs or place impermeable materials, such as concrete or plastic, over the drainfield.
- ...use cleaning chemicals in moderation and only according to manufacturer's directions.

### **Don't**

- ...flood irrigate over your system or drainfield area. The best way to irrigate these areas is with sprinklers.
  - ...use caustic drain openers for clogged drains. Use boiling water or a drain snake to clean out clogs.
  - ...enter a septic tank. Poisonous gases or a lack of oxygen can be fatal.
  - ...use septic tank additives. They are not necessary for the proper functioning of your tank and they do not reduce the need for pumping. In fact, some additives can even harm your system.
  - ...flush harmful materials into your tank. Grease, cooking oil, coffee grounds, sanitary napkins, and cigarettes do not easily decompose in septic tanks. Chemicals, such as solvents, oils, paints, and pesticides, are harmful to your systems operation and may pollute groundwater.
  - ...use a garbage disposal. Using a garbage disposal will increase the amount of solids entering the septic tank and will result in the need for more frequent pumping.
-



**Map your septic system here**



## **For More Information**

If you need to obtain a permit for a new or replacement septic system, or if you have questions about septic systems and their operation and maintenance, please contact your local health district.

**Panhandle District Health Department**  
8500 N. Atlas Road  
Hayden, ID 83835  
208-415-5100

**North Central District Health Department**  
215 10<sup>th</sup> Street  
Lewiston, ID 83501  
208-799-0353

**Southwest District Health Department**  
920 Main Street  
Caldwell, ID 83605  
208-455-5400

**Central District Health Department**  
707 N. Armstrong Place  
Boise, ID 83704  
208-327-7499

**South Central District Health Department**  
1020 Washington Street North  
Twin Falls, ID 83303  
208-734-5900

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**Southeastern District Health Department**  
1901 Alvin Ricken Drive  
Pocatello, ID 83201  
208-239-5270

**District 7 Health Department**  
254 "E" Street  
Idaho Falls, ID 83402  
208-523-5382

## West Mountain Sewer and Water - Reuse Permit M-117-03 - Regulatory Status

Danielle Robbins <Danielle.Robbins@deq.idaho.gov>

Thu 2/3/2022 3:30 PM

To: Lori Hunter <lhunter@co.valley.id.us>

Cc: [REDACTED]

📎 6 attachments (7 MB)

West Mountain Sewer and Water - Reuse Permit M-117-03 - Regulatory Status.pdf; Drinking water Review 2.pdf; 2.1 Pages from 2019AGD622 West Mountain Sewer & Water (BlackHawk)- Wastewater Facility Plan 2006 Addendum-3.pdf; 3.2 Pages from 2019AGD622 West Mountain Sewer & Water (BlackHawk)- Wastewater Facility Plan 2006 Addendum-2.pdf; Wastewater Review 2.pdf; 3.1 Pages from 2019AGD622 West Mountain Sewer & Water (BlackHawk)- Wastewater Facility Plan 2006 Addendum.pdf;

**CAUTION:** This email originated from outside of the organization. Do not click links or open attachments unless you recognize the sender and know the content is safe.

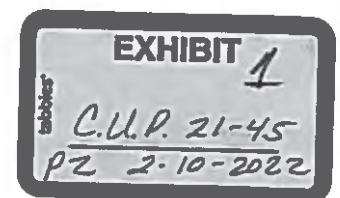
To Whom It May Concern:

Please see the attached letter and enclosures from Valerie Greear.

Sincerely,

Dani Robbins | Administrative Assistant  
Idaho Department of Environmental Quality | Boise Regional Office  
1445 North Orchard Street  
Boise, Idaho 83706  
Office: (208) 373-0177  
Email: [Danielle.robbsins@deq.idaho.gov](mailto:Danielle.robbsins@deq.idaho.gov)  
<http://www.deq.idaho.gov/>

*Our mission is to protect human health and the quality of Idaho's air, land, and water.*





STATE OF IDAHO  
DEPARTMENT OF  
ENVIRONMENTAL QUALITY

1445 N. Orchard Street, Boise ID 83706  
(208) 373-0550

Brad Little, Governor  
Jess Byrne, Director

February 3, 2022

By email: [lhunter@co.valley.id.us](mailto:lhunter@co.valley.id.us)

Valley County Planning & Zoning  
219 N. Main Street, PO Box 1350  
Cascade ID 83611

Subject: West Mountain Sewer and Water

To Whom It May Concern:

The Idaho Department of Environmental Quality (DEQ) is providing this letter to summarize the status of engineering submittals and the recycled water reuse permit with respect to the West Mountain Sewer and Water (WMSW).

DEQ first issued a recycled water reuse permit to Payette River Estates in 1992, which was transferred to WMSW on July 25, 2005. WMSW is currently in good standing with respect to their Reuse Permit M-117-03, and DEQ is in the process of completing a renewal permit for WMSW.

Reuse Permit M-117-03 allows WMSW to irrigate up to 11.81 acres of forested land, of which WMSW currently is able to use 8.5 acres. The land required to properly dispose of water led DEQ to place a limit on the number of homes that could be served by WMSW. In 2010, DEQ calculated this to be 124 equivalent dwelling units (EDU), and this limit is included in Section 4.5 of Reuse Permit M-117-03.

DEQ understands that the lots sold within the developments served by WMSW exceed 124 at this time. Before connecting more than 124 homes to the wastewater treatment facility, WMSW will, at a minimum, be required to provide an engineering evaluation of the existing treatment facility and land application acreage, and the existing and projected wastewater flows, to determine the actual existing treatment capacity.

A Facility Plan, submitted to and approved by DEQ, is required by the "Wastewater Rules" (IDAPA 58.01.16) prior to building or expanding a wastewater treatment facility. The most recent Facility Plan for WMSW is from 2005, with an addendum submitted in 2006. The Facility Plan indicates that sanitary restrictions have been lifted on 155 lots, but this does not supersede the limit in Reuse Permit M-117-03. In order to address this significant impending problem with overcommitment of the current treatment facilities, DEQ will be setting compliance due dates for planning and upgrades in the upcoming permit for WMSW.

The 2005 Facility Plan and 2006 Addendum are outdated and need to be updated before any future development of the WMSW facilities can occur. For information purposes, the 2005 Facility Plan includes plans to upgrade the wastewater treatment facilities in two phases to reach a total of 232 EDU in Phase 2, and then 412 EDU in Phase 3, to accommodate development of Blackhawk on the River (BOTR). Addition of a second primary treatment pond was completed in 2017 as a step towards Phase 2 treatment capacity.

The 2006 Addendum evaluated addition of the Red Ridge Development (Red Ridge) for a total of 1,212 EDU. The 2006 Addendum concluded that the three developments should jointly pursue a connection to the North Lake Recreational Water and Sewer District (NLRWSD) or Payette Lakes Recreational Water and Sewer District (PLRWSD) during development of Red Ridge. Short term expansion options were considered to allow lifting of sanitary restrictions on some Phase 2 lots, which would necessitate upgraded treatment and/or additional land application areas.

Options considered in the 2006 Addendum, other than connection to NLRWSD or PLRWSD, include upgrading the wastewater treatment facilities to produce recycled water of higher quality for use as irrigation of common areas or a golf course, or the use of rapid infiltration of treated water instead of irrigation. Figures included in the 2006 Addendum are attached. Any of these options include several phases of engineering and permitting requirements.

Engineering submittals for the BOTR Public Water System (PWS) were approved between 2005-2007. The system consists of two wells. The engineering report states that the PWS is to serve drinking water and provide fire flow to 132 lots and a recreation center within BOTR. It does not appear to address any expansion; therefore, any use of this system to provide drinking water or fire flow to additional connections will require a Drinking Water Facility Plan, as required by the "Idaho Rules for Public Drinking Water Systems" (IDAPA 58.01.08), as well as subsequent engineering submittals as necessitated by the proposed project.

Attached for your reference are flow charts showing the process of engineering reviews through DEQ.



Please reach out with questions regarding the regulatory status of the wastewater and drinking water facilities serving these existing and proposed communities. I can be reached at (208) 373-0550.

Sincerely,



Valerie A. Greear, PE  
Water Quality Engineering Manager

VG:dr  
2022AGD466

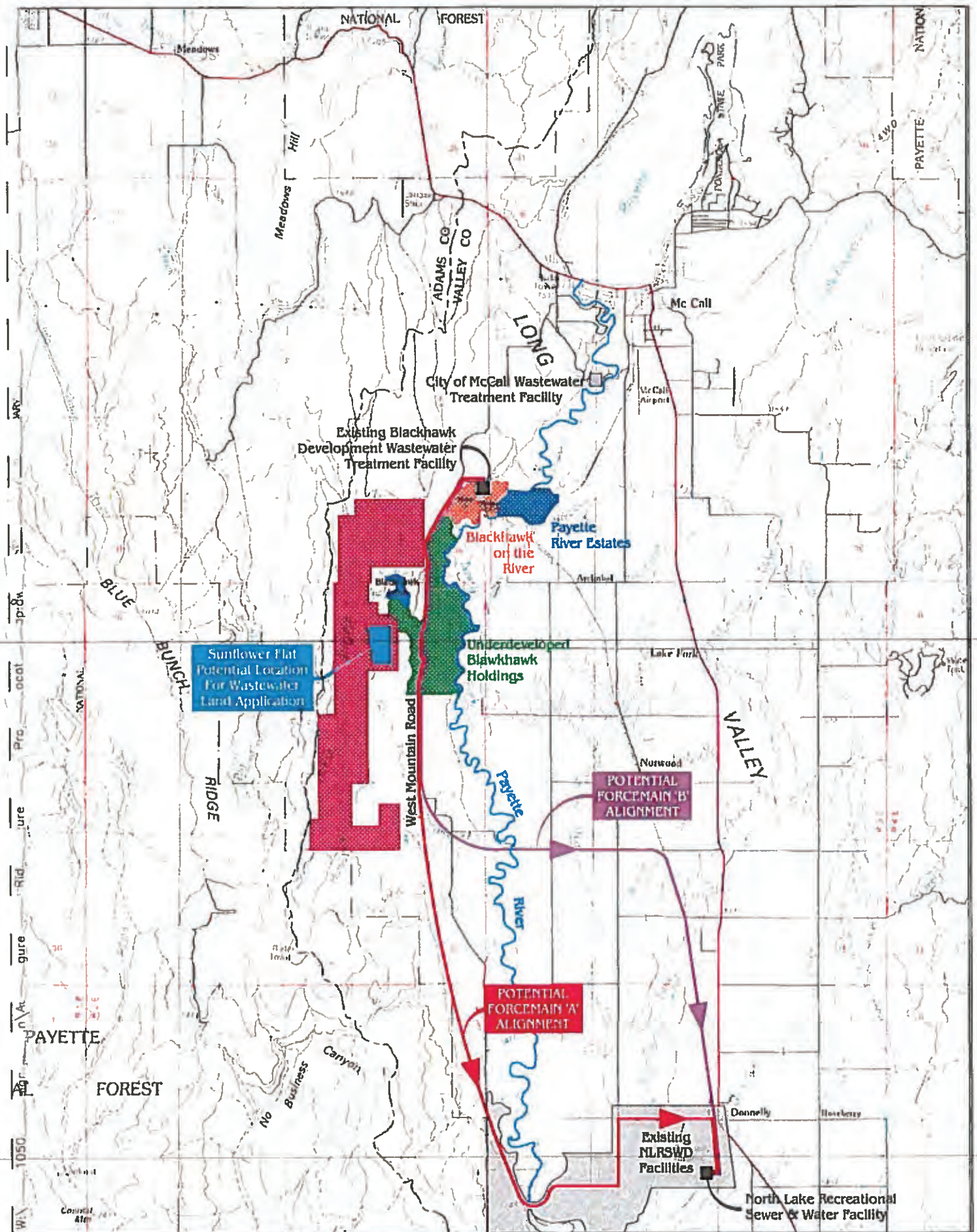
Attachments: 2006 Addendum Figures, Wastewater and Drinking Water Engineering review  
flow charts

c: Brian Dickens, West Mountain Sewer and Water

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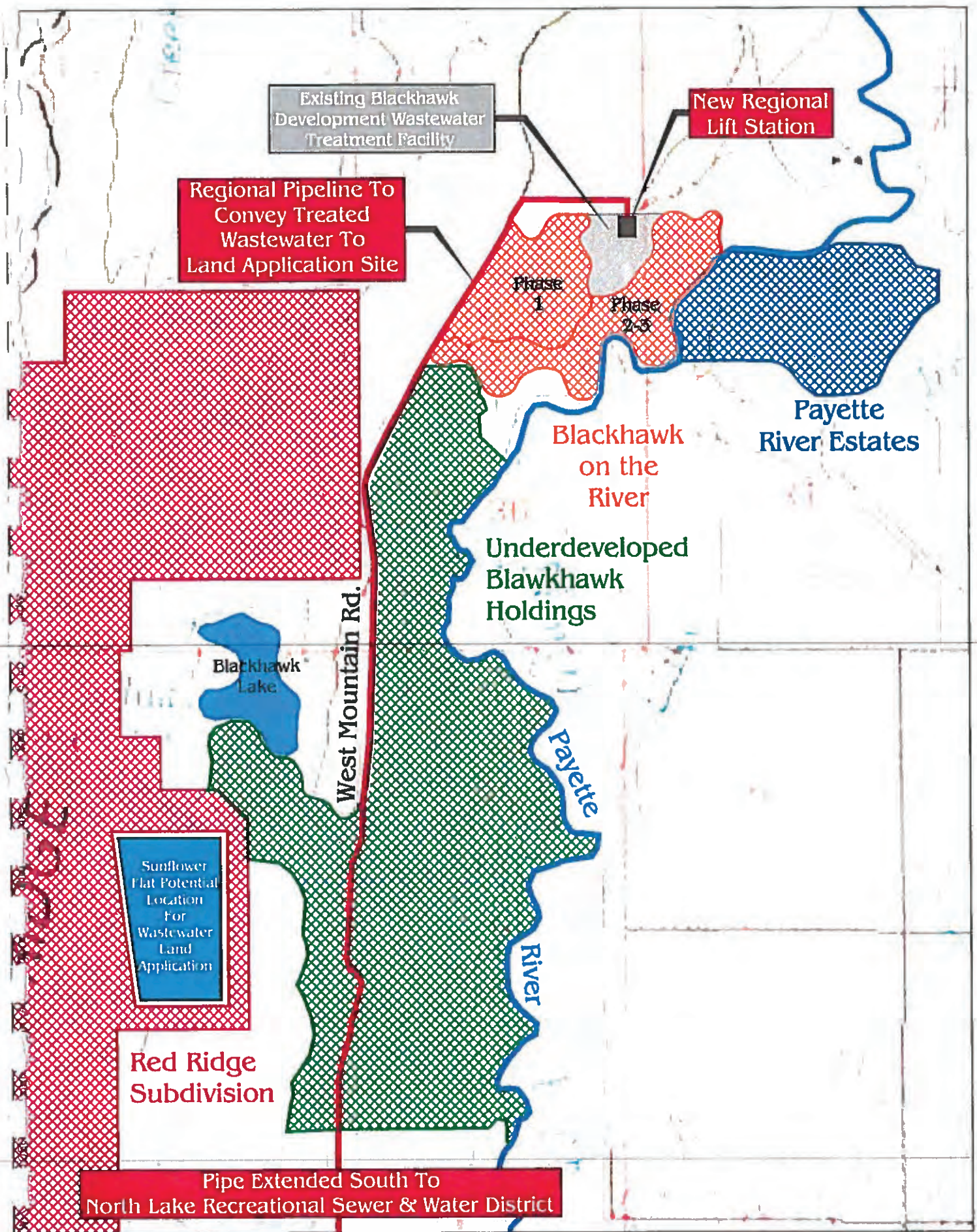
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**FIGURE 2.1 - PROJECT LOCATION MAP**





**FIGURE 3.2 - Red Ridge Land Application**



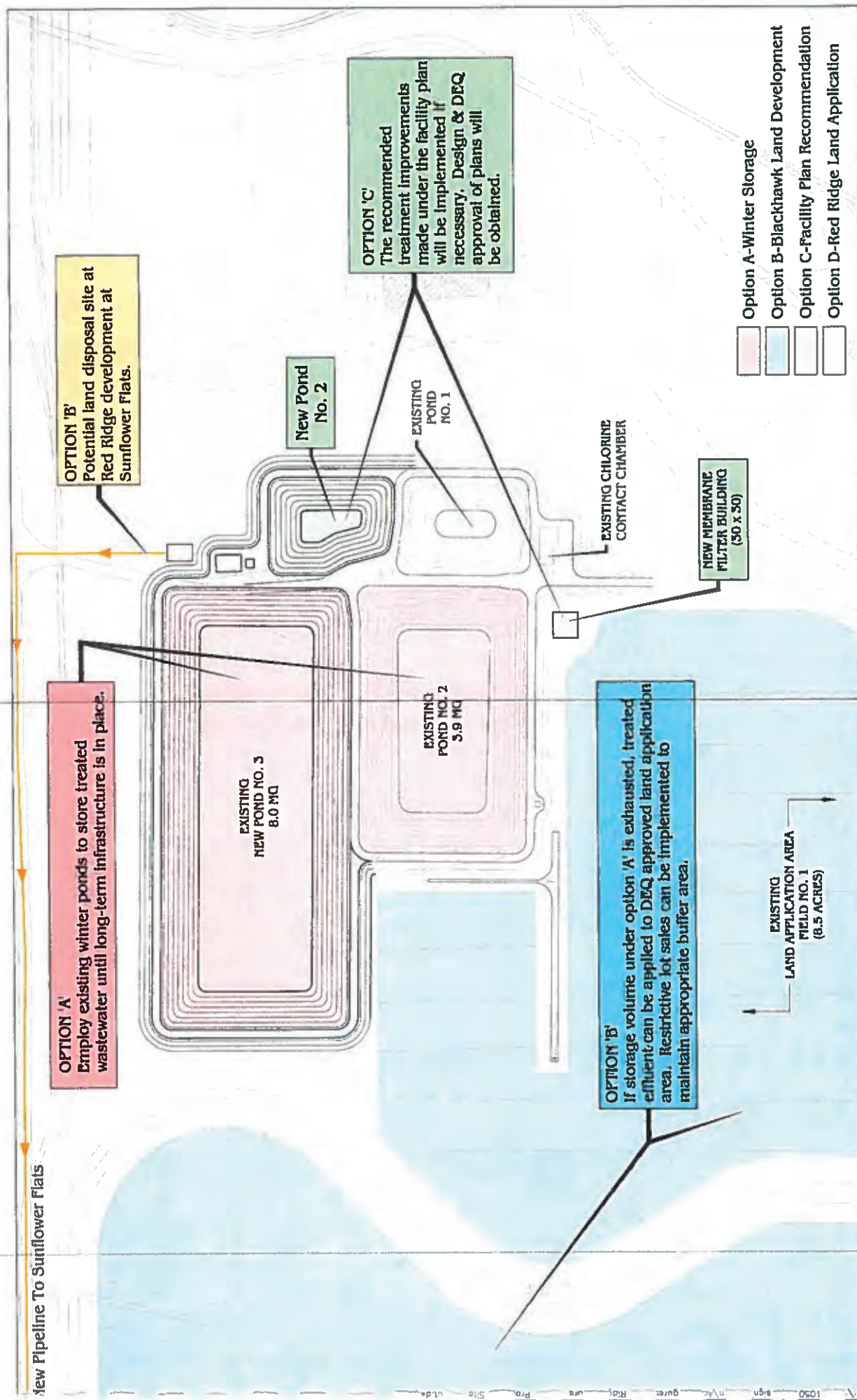
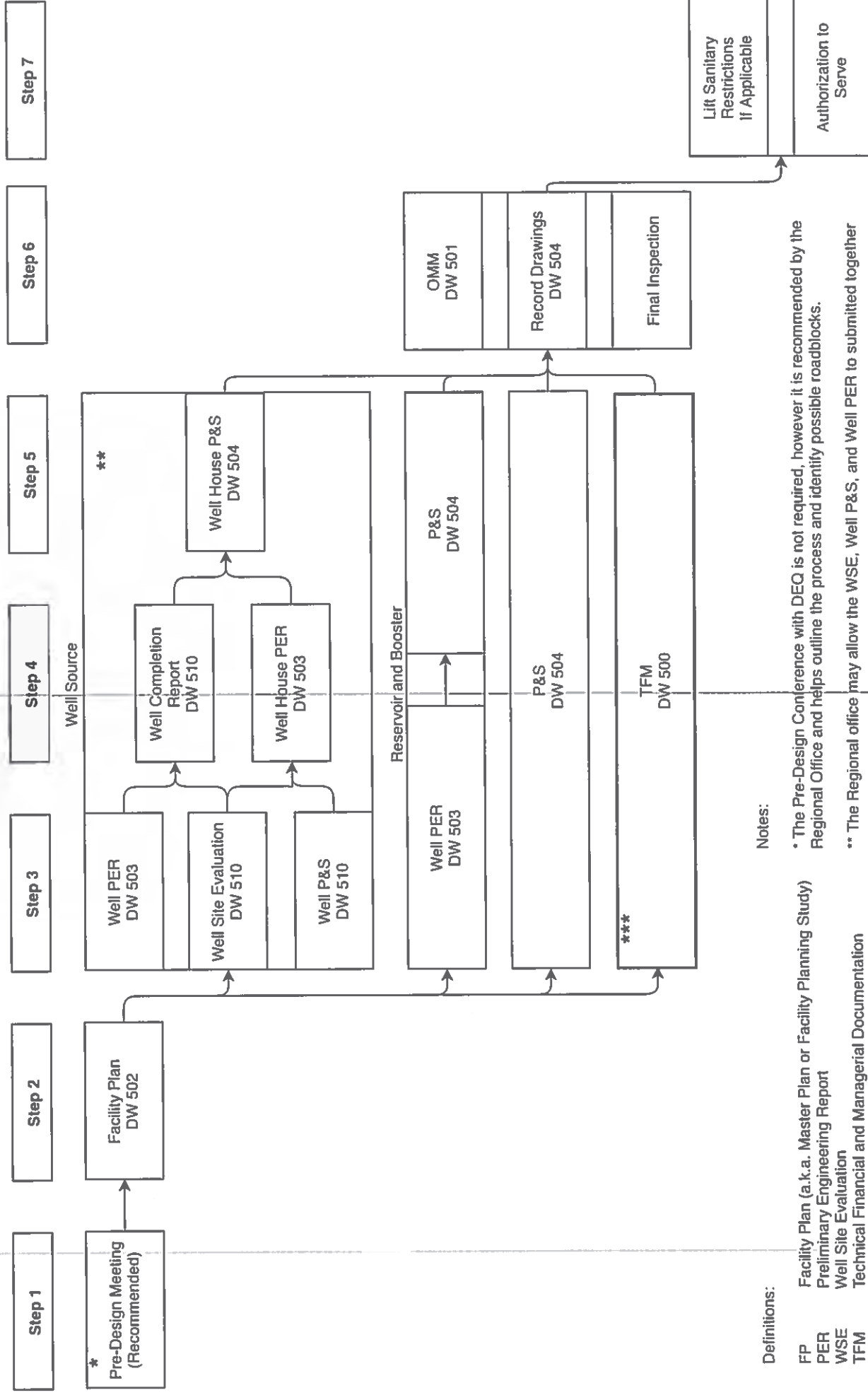


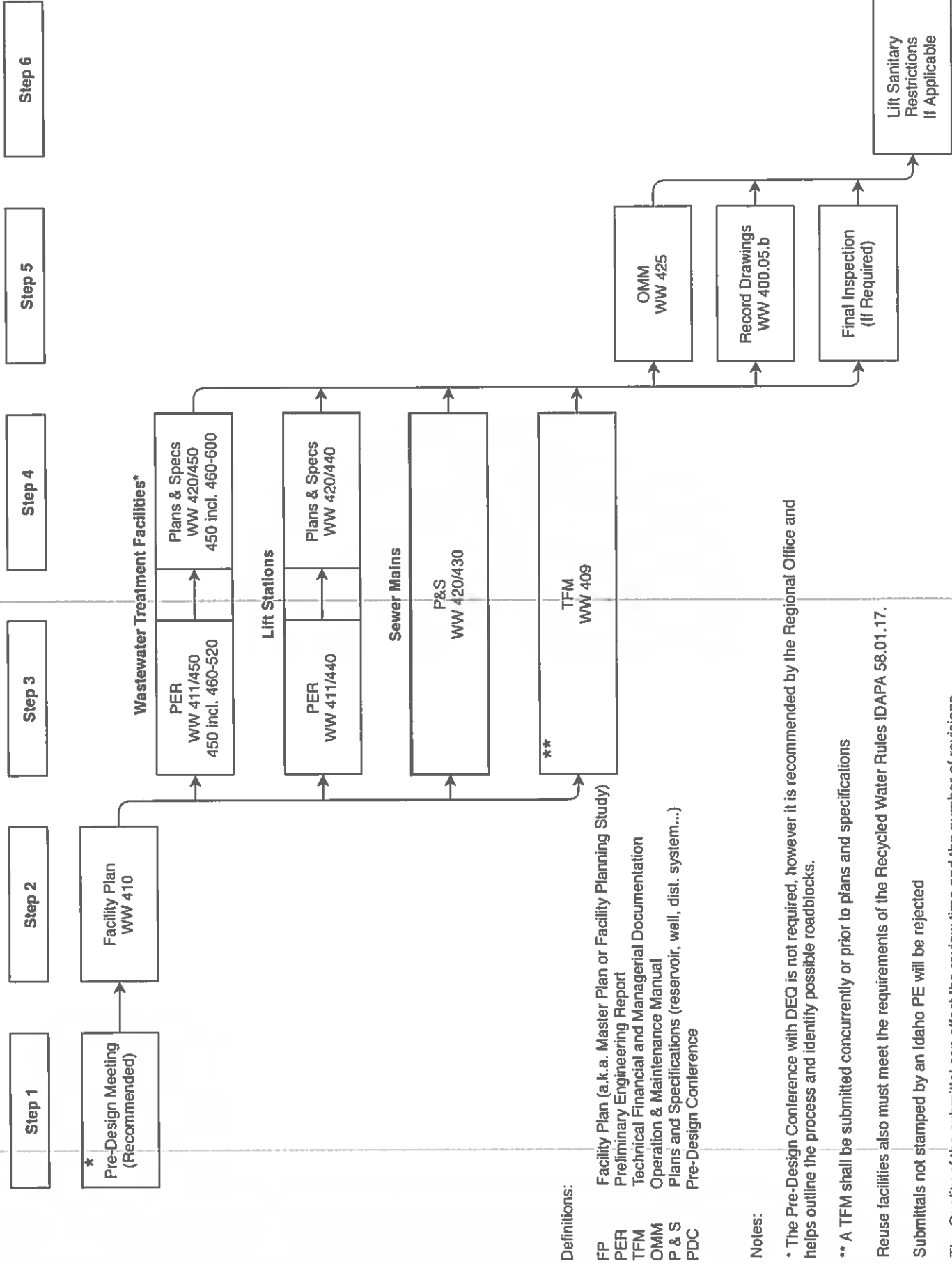
FIGURE 3.1 - SHORT TERM WASTEWATER MANAGEMENT OPTIONS

# Drinking Water System General Submittal and Review Process Idaho DEQ





# Waste Water System General Submittal and Review Process Idaho DEQ





## Valley Soil & Water Conservation District

P.O. Box 580  
209 N Idaho Street  
Cascade, ID 83611

February 3, 2022

Valley County Planning and Zoning Commissioners  
c/o Cynda Herrick  
219 N. Main St.  
Cascade, Idaho 83611

**Subject: CUP 21-45 RedRidge Preserve and CUP 21.46 Bharn Event Center**

Dear Commissioners,

Valley Soil & Water Conservation District has concerns with two applications: C.U.P. 21-45 RedRidge Preserve and C.U.P 21-46 Bharn Event Center regarding soil types and individual septic systems. The District has invested hundreds of thousands in State and Federal grant funds along with countless volunteer hours to address water quality and nutrient loading in the NFPR watershed. TMDL goals set by the WAG have never been met. Adding more septic systems to soils not adapted to septic systems will not hasten the journey toward meeting TMDL goals.

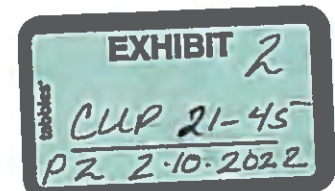
CUP 21-45 RedRidge Preserve-Preliminary Plat: The two major soil types underlying this property are Demast loam (#15) and Tica very cobbly loam (#58). The USDA soil survey rate both soil types as very limited within the Septic Tank Absorption Fields table. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use- in this case septic tank absorption fields. High numbers of septic systems without proper maintenance (i.e. 3-5 year pump-out) could lead to nutrient inputs to the North Fork Payette River and Lake Cascade, which is already having problems with algae blooms. The District would highly recommend that alternatives other than individual systems be considered and installed such as a central septic system.

CUP 21.46 Bharn Event Center: the soil type that underlies the proposed location of this center is Roseberry (#47) which has a rating of very limited within the Septic Tank Absorption Fields table. "Very limited" indicates that the soil has one or more features that are unfavorable for the specified use- in this case septic tank absorption fields. The District would highly recommend that another type of septic tank system be considered to minimize the risk of nutrients reaching the waterbody draining to the Lake Cascade wetland area, less than 1000 feet distance. Furthermore, the application does not indicate that Animal Waste Storm Water Pollution Prevention Plans (SWPPP) or measures to manage manure and eliminate animal waste from entering tributary drainages of the West Mountain Subwatershed and Cascade Reservoir, therefore a permit condition based on a SWPPP is recommended.

IDEQ and WAG implementation plans detail information on efforts to manage nonpoint sources with useful septic information and can be referenced at the link below:

<https://www.deq.idaho.gov/water-quality/surface-water/total-maximum-daily-loads/payette-river-north-fork-subbasin/>

Additionally, the Cascade Reservoir Watershed TMDL Five-Year review can be referenced for information on nutrient issues. The reservoir is listed for phosphorus, a driving factor in harmful algal blooms. Septic is a likely contributor to this impairment, and any additional nutrient sources added to the watershed will



ultimately influence the water quality in Cascade Reservoir. Sewer connections and treatment have shown to be best practices and improve water quality compared to septic.

With Respect,

Valley Soil & Water Conservation District Board of Supervisors

Art Troutner, Chairman  
Paul Kleint, Vice Chairman  
John Lillehaug, Treasurer  
Bill Leaf, Secretary  
Colt Brown, Supervisor

VSWCD/df