The Freshwater Trust

July 30, 2015

Lower Boise River Technical Analysis

Evaluation of agricultural best management practices, on-field conditions, and hydrologic connection to support water quality trading

Final Deliverable

Introduction

The wastewater treatment facilities (WWTFs) of the Lower Boise River will soon face new total phosphorus permit limits. A Total Maximum Daily Load (TMDL) for phosphorus was recently completed by the Idaho Department of Environmental Quality (IDEQ), with submission to Region 10 of the U.S. Environmental Protection Agency (EPA) expected in summer 2015. The Lower Boise Trading Framework (LBTF) was originally developed to facilitate water quality improvements through water quality trading. While the LBTF was developed in the early 2000s, it has not yet been used for NPDES compliance. In the decade since completion, many other water quality trading programs, approaches and, importantly, new analytical tools and infrastructure have been developed to better support water quality trading for phosphorus and temperature. In addition, the state of Idaho has been engaged in a regional process that developed a set of draft regional recommendations for trading in the Pacific Northwest.[1] As communities in the Lower Boise watershed begin to evaluate facility-specific approaches to meeting new phosphorus limits, it makes sense to incorporate the new tools and learning to ensure that trading programs remain a secure compliance alternative integrated as a component in an overall water quality improvement strategy.

While the phosphorus TMDL has focused on instream, ambient water quality conditions, attention must also be paid to on-field conditions. To be effective, water quality trading programs need to accurately capture on-the-ground conditions at nonpoint source locations. This includes selection and calibration of the correct models, assessment of how and where particular best management practices (BMPs) would be most effective, calculation of the water quality benefits that can and should be attributed to on-field and watershed-scale conservation actions, and determination of eligibility criteria to engage in trading. As part of this scope of work, The Freshwater Trust (The Trust) has completed the following four tasks:

1. Evaluation of the effectiveness and uncertainty rates associated with agricultural BMPs to reduce phosphorus loading
2. Hydrologic connection assessment (subbasin "plumbing") to support eligibility requirements for farm fields
3. Assessment of field-scale and watershed-scale models that can be used in a water quality trading program for phosphorus

[1] More information on the Joint Regional Recommendation can be found here: http://willamettepartnership.org/success-stories/regional-recommendations-water-quality-trading.

4. Evaluation of BMP effectiveness at the farm-field level to support effort to prioritize BMP implementation

These methodologies and the results of these tasks are described below.

Task 1: Evaluation of Best Management Practices

In order to update the BMPs currently included in the LBTF, The Trust carried out a comprehensive evaluation of the effectiveness and uncertainty rates listed in the original framework (see Ross & Associates Environmental Consulting, 2000). This evaluation was supplemented through the use of the Nutrient Tracking Tool (NTT), which is a USDA-sponsored computer-based nutrient transport model that estimates edge-of-field sediment and nutrient runoff based on a variety of agricultural management practices. Additionally, an estimate of the effectiveness of multiple, simultaneously employed BMPs is included, along with a brief overview of the modeling tools.

EVALUATION OF ELIGIBLE PRACTICES

The Trust reviewed the agricultural BMPs eligible for trading in the Lower Boise in order to: a) ensure that all of the practices included in the 2002 document "Best Management Practice (BMP) List for the Lower Boise River Pollution Trading Program" (ISCC, 2002) are still appropriate for the current situation in the Treasure Valley based on prevalent cropping and management practices in the region; and b) evaluate other practices that could be added to this list in order to give landowners additional options to participate in trading programs.

Evaluation of Current List of Eligible Agricultural BMPs

In order to evaluate the list of eligible practices, each BMP was categorized based on the crop type(s) and management practice(s) to which it corresponds. These crop types and management practices were then assessed in order to ensure that no substantial changes—economic, environmental, cultural, or political, for example—had occurred in the past thirteen years that would render them, and their corresponding BMPs, obsolete. In addition, a review of the scientific literature was carried out in order to track any major shifts in the understanding of the effectiveness and applicability of each of these practices. This process also included a review of cropping and irrigation trends in the Treasure Valley, and consultation with local experts. Finally, each BMP was assessed based on the ability of an implementing agency to understand how to accurately estimate its effectiveness.

The conclusions of this review were as follows:

- → Twelve of the thirteen agricultural BMPs included in the Lower Boise River Pollution Trading Program remain viable options for the updated LBTF.
- → Conservation Crop Rotation (NRCS Practice Code 328) is not recommended for a nutrient trading program. This recommendation is based on the high degree of uncertainty in the effectiveness of the practice. This high degree of uncertainty is due in part to ambiguity in the length of time, and the number and type of rotations required in order to generate trading credits.
- → As stated in the original program documents, the effectiveness of Nutrient Management (NRCS Practice Code 590) is difficult to estimate due to "numerous complexities" such as the highly site-specific nature and the dynamic and responsive approach that is

integral to the practice. Furthermore,, NRCS guidance on water quality enhancement activities states that "nutrient management may be a component of a conservation management system and is **most effective when used in conjunction with crop rotation, residue management, pest management, conservation buffer practices, and/or other practices** needed on a site-specific basis to address natural resource concerns and the landowner's objectives."(NRCS, 2008) Therefore, despite the inherent difficulty in establishing an effectiveness rate for nutrient management as a single, discrete practice, The Trust still considers Nutrient Management Planning a key practice to incorporate into the updated LBTF. For the purposes of this analysis, Nutrient Management Planning is considered to play the same role as it did in the original framework – it is not assigned an efficiency rate, but is instead considered to be a complementary practice that enhances the outcomes of other BMPs when simultaneously implemented.

→ Due to the increasing prevalence of dairy and other livestock operations in the Treasure Valley, special consideration should be given to the compatibility of eligible BMPs with practices related to the collection, storage, transport, and/or spreading of manure. Although there are a number of BMPs that are exclusive to livestock operations, nearly all of the eligible practices included in the original trading framework can be applied to both crop and livestock operations. All participating farms – whether it be a crop farm, a livestock operation, or some combination of the two – will consult with local experts prior to the implementation of eligible BMPs. During this consultation period any adjustments to the timing and/or location of the relevant practice standard can be made so as to maximize the BMP's conservation benefits. For this reason, The Trust believes that the existing list of practices offers sufficient flexibility to allow for the participation of the majority of agricultural operations in the area and to achieve nutrient runoff reductions in an efficient and cost-effective manner.

Evaluation of Potential Additions to List of Eligible Agricultural BMPs

Based on cropping and management practices that are commonly employed in the Treasure Valley, The Trust recommends adding one additional practice to the LBTF-eligible BMP list: Cover Cropping (NRCS Practice Code 340). In order to inform its potential for nutrient trading credit generation, cover crop effectiveness was evaluated alongside all other eligible BMPs in the literature review described in the following section.

Growing cover crops is a commonly implemented agricultural best management practice that produces a filtering effect on movement of sediment and sediment-attached pollutants (NRCS, 2011). The practice involves growing a crop of grass, small grain, or legumes, usually during the non-crop period, in order provide additional vegetative groundcover that promotes water infiltration and recycles nutrients for succeeding crops. Cover crop varieties well-suited for high-desert farming systems have been tested under Idaho growing conditions, and guidance on practice implementation is readily available throughout the state (Hunter et al., 2014).

Filter Strips and Nutrient Management Planning: Complementary or "Enhancement" BMPs

As stated above, The Trust believes that continued inclusion of the nutrient management planning BMP will benefit trading in the Lower Boise, particularly when implemented in conjunction with other practices, as recommended by the NRCS. Another important agricultural BMP, vegetative filter strips, can decrease the uncertainty inherent in other BMPs by creating a physical barrier between the field and the adjacent surface water body, thereby mitigating loading from storm events and other high loading situations. As explained in the evaluation below, however, there is a large degree of variability in the overall effectiveness of filter strips. This makes the process of estimating the sediment reduction achieved as a result of filter strip implementation—a key component of a nutrient trading program—extremely difficult. Moreover, because the lifespan of a filter strip is inversely proportional to the load flowing into it, it is a practice best employed in conjunction with other BMPs that are designed to reduce erosion and agricultural chemical loss on the field. Because these BMPs help to reduce the uncertainty associated with other more readily measurable BMPs, and because these BMPs are both relatively low-cost and involve lesser degrees of landowner commitment than other practices, it may make sense for a landowner to implement one or both of these practices in conjunction with other BMPs to generate credits.

EVALUATION OF EFFECTIVENESS AND UNCERTAINTY RATES

In order to update the effectiveness values in the trading framework, The Trust reviewed peer-reviewed publications, technical documents, and reports published in 2002 or later. The results of this review are documented in Table 1. The Trust then outlines its proposed effectiveness rate modification methodology and recommends revised effectiveness rates for BMPs (summarized in Table 2). The Trust validated these revised effectiveness rate suggestions with model runs of USDA's NTT.

Literature Review of BMP Effectiveness and Uncertainty Rates

Relevant literature was identified by searching a variety of agricultural databases, including AGRICOLA, AGRIS, and AGROVOC. These results were supplemented by searching more general databases, such as ScienceDirect, Scopus, and Google Scholar. An example of the Boolean search terms used is: "agriculture* AND ('best management practice' OR 'BMP' OR "bmp name") AND (effectiveness OR efficiency)." Only literature published in 2002 or later was considered for review. Additional papers were identified from citations within the reviewed literature on the rare occasion that the citation was for a relevant paper that had not been identified during the initial search. That literature is summarized in Table 1.

Due to the paucity of relevant literature specifically focused on BMP effectiveness in southern Idaho, the literature review considered research from all regions, both in the United States and abroad. Since BMP effectiveness is often highly site-specific, the results of research carried out in locations outside of southern Idaho are not directly translatable to the Lower Boise River watershed. Instead, The Trust's review looked for patterns in effectiveness rates for a given BMP based on climate, soil type, and cropping systems. Few clear patterns emerged. Therefore, The Trust assumed that the variance in effectiveness rates was due primarily to implementation variability and/or differences in site suitability. Relying on this assumption, The Trust interpreted the degree of variance in effectiveness rates observed in the literature review for a given practice to reflect the "uncertainty" value for that practice.

Table 1. Agricultural BMP effectiveness literature review.

Reduction in Total Phosphorus (%)	Location	Method	Reference	Notes
Polyacrylamide (450)				
50-80%	Various	Lit Review	Bjorneberg & Leytem, 2005	Furrow Irrigation
90-95%	OR	Field Plot	Shock et al., 2007	Furrow Irrigation
70%		Field Plot	Bjorneberg et al., 2003	Sprinkler Irrigation
70%*	Western US	Tech Review	Sojka et al., 2007	Full season
50%*	Western US	Tech Review	Sojka et al., 2007	Part season
Filter Strips (393)				
14-85%	Worldwide	Lit Review	Dorioz et al., 2006	
50%	Various	Lit review	Novotny, 2003	
40-70%	Various	Lit Review	D. Bjorneberg & Leytem, 2005	
80%	Italy	Field plot	Borin et al., 2005	6 m "buffer strips"
86%	Canada	Field plot	Duchemin & Hogue, 2009	
50-98%	Canada	Field plot	Gharabaghi et al., 2006	>90% of sediment trapped in first 5 m
94%, 77%	Canada	Field plot	Goel, 2004	Sediment bound and soluble P, respectively
78-91%	IA	Field plot	Lee et al., 2003	
86-94%	IL	Field plot	Schoonover et al., 2006	Giant cane
25.7%	TX	Model	Tuppad et al., 2010	30 year annual average
21%	IN	Model	Arabi et al., 2008	
93%		Model	Gitau et al., 2005	
10%	Greece	Model	Panagopoulos et al., 2011	
17%	MI	Model	Vennix & Northcott, 2004	
Straw in Furrows (484)				
52-71%	Various	Lit Review	Sojka et al., 2007	
85%*	Western US	Tech Review	Bjorneberg et al., 2007	Full season straw mulch
65%*	Western US	Tech Review	Bjorneberg et al., 2007	Part season straw mulch
Strip-till and no-till (329)				
44-91%	AR	Lit Review	Merriman et al., 2009	
35-80%	Various	Lit review	Novotny, 2003	
0 – 67%	Various	Lit Review	Fawcett & Caruana, 2001	No reduction for Group D soils; >50% for B and C
86-90%	MS	Field study	Cullum et al., 2007	With (86%) and without (90%) grass hedges
-12%	Canada	Paired Watershed	Tiessen et al., 2010	Conservation tillage; "exports of P increased by 12%"
23%	IN	Model	Arabi et al., 2008	
-3.3%%	TX	Model	Tuppad et al., 2010	30 year annual average
95%	?	Model	Gitau et al., 2005	
12-25%	TX	Model	Santhi et al., 2006	
90%	IA	Model	Zhou et al., 2009	No till and strip till
10%	MN	?	Dalzell et al., 2004	
85-90%*	Western US	Tech Review	Bjorneberg et al., 2007	No-Till
Sediment Basin (350)				
None				

Reduction in Total Phosphorus (%)	Location	Method	Reference	Notes
Underground Outlet (620)				
None				
Nutrient Management Plan (590)				
60%	FL	Paired Watershed	Rice & Izuno, 2002	
20-90%	Various	Lit review	Novotny, 2003	
53-78%	TX	Model	Santhi et al., 2006	
8%	Greece	Model	Panagopoulos et al., 2011	
Constructed Wetland (656)				
-76-80%	Various	Lit review	Kadlec & Wallace, 2009	
90%	Ireland	Field study	Scholz & Hedmark, 2010	
59%	MD	Field study	Jordan et al., 2003	Year 2 - 0% removal
Cover Crop (340)				
54-94%	Various	Lit Review	Kaspar & Singer, 2011	
26%	WI	Field Study	Jokela & Casler, 2011	
10%	IN	Model	Arabi et al., 2008	
80%*	Western US	Tech Review	Bjorneberg et al., 2007	Seasonal residue mgmt.

*Converted from "conservation practice adjustment factor"

Proposed Modification Methodology

Because of the numerous dissimilarities (e.g., sample size, methodology, model or field study, etc.) in the literature reviewed, The Trust determined that using the mean or median effectiveness from all reviewed studies for a given BMP would not be appropriate for this task. Instead, The Trust modified practice effectiveness rates that showed high levels of uncertainty by either 5 percentage points or 10 percentage points. The 10 percentage point limit was set in order to acknowledge the local expertise and site-specific considerations that informed the rates in the original 2000 framework.

The following criteria were used to determine the magnitude of the final revision:

> **No Change:** The range of BMP effectiveness in the reviewed literature spanned less than 40 percentage points, AND the midpoint of this range was within 5 percentage points of the original rate.
>
> **5 Percentage Point Revision:** The range of BMP effectiveness in the reviewed literature was between 40 and 60 percentage points; AND/OR the midpoint of this range was between 5 and 10 percentage points of the original rate.
>
> **10 Percentage Point Revision:** The range of BMP effectiveness in the reviewed literature was 60 percentage points or greater; AND/OR the midpoint of this range was more than 10 percentage points different than the original rate.

For example, the 2000 trading framework listed filter strip (NRCS Practice Code 393) as having a net effectiveness rate of 40 percent.[2] The Trust's literature reviewed identified filter strip effectiveness rates as low as 10 percent and as high as 98 percent (range=88; midpoint=54). Because at least one of the criteria listed above for a 10 percentage point revision—a range greater than 60 percentage points and midpoint more than 10 percentage points from original rate—has been met, The Trust suggests that the filter strip effectiveness rate be revised from 40 percent to 30 percent. A summary of the revised effectiveness rates can be found in Table 2. The literature effectiveness rates summarized in the third column of Table 2 are assembled from Table 1.

[2] Rate includes the uncertainty discount of 15 percent, as stated in the nutrient trading framework.

Table 2. Original and revised BMP effectiveness rates.

BMP (NRCS Code)	ISCC Effectiveness (uncertainty), %	Lit Review Effectiveness Range, %	Proposed Revised Effectiveness,* %
Polyacrylamide (450)	95 (10)	50 to 95	80
Filter Strip (393)	55 (15)	5 to 93	35
Sprinkler Irrigation (442)	100 (10)	NA	90
Microirrigation (441)	100 (2)	NA	98
Tailwater Recovery (447)	100 (5)	NA	95
Straw in Furrows (484)	90 (20)	52 to 85	65
Strip-Till or No-Till (329)	90 (10)	-3.3 to 91	70
Sediment Basin, Field Scale (350)	75 (10)	NA	65
Sediment Basin, Watershed Scale (350)	65 (15)	NA	50
Underground Outlet (620), years 1-2	85 (15)	NA	70
Underground Outlet (620), after year 2	65 (25)	NA	40
Surge Irrigation (449)	50 (5)	NA	45
Nutrient Management (590)	NA	NA	NA
Constructed Wetland, Farm Scale (656)	90 (5)	-76 to 90	75
Constructed Wetland, Watershed Scale (656)	NA	-76 to 90	NA
Cover Crop (340)	NA	10 to 94	60

= no change; = revised 5 percentage points downward; = revised 10 percentage points downward; = not included in original trading framework

* "uncertainty" values have already been subtracted

Validation Using the Nutrient Tracking Tool (NTT)

In order to evaluate the accuracy of the proposed revisions to the effectiveness rates in Table 2, The Trust used NTT to simulate the implementation of various suites of agricultural BMPs in the Mason Creek subwatershed. The Trust selected Mason Creek for this validation exercise because there are minimal point source impacts to water quality in Mason Creek, meaning water quality is primarily driven by nonpoint source loads. This makes Mason Creek an ideal area to compare measured water quality data at the mouth and modeled current conditions.

NTT is a web-based field model that compares agricultural management systems in order to calculate a change in nutrient loss, sediment loss, and crop yield. Users can enter pre-BMP conditions and alternative management systems, which are then simulated and compared to produce a report showing the nitrogen, phosphorus, sediment loss potential, and crop yield difference between the two.[3] By adjusting parameters for management practices and structural changes, users can simulate the pollutant reductions achieved by a variety of agricultural BMPs. The estimates are derived from USDA's Revised Universal Soil Loss Equation 2 (RUSLE2).

The BMPs simulated for this analysis include the following:

- → Conversion from furrow irrigation to sprinkler irrigation
- → Conversion from furrow irrigation to micro or drip irrigation
- → Conversion from conventional tillage to no-till

[3] http://nn.tarleton.edu/NTTWebARS

→ Planting a fall cover crop
→ Planting/installing a filter strip

The reports produced by NTT are "edge-of-field" estimates based on the physical characteristics and historical climate of the geographic "area of interest" (AOI). Users can select their AOI using USDA's Web Soil Survey,[4] or use the associated soil databases to create a custom field site by selecting a soil type, area and slope.

In order to simulate management-change scenarios for the Mason Creek area, The Trust first evaluated the common characteristics of agricultural fields in the watershed. These characteristics include the slope, area, and soil type of the agricultural fields. The summary statistics for these characteristics are outlined in Table 3 below, and the parameters chosen for the NTT simulations are listed below Table 3. Because a soil's erodibility, or "K factor," is a major driver of the soil loss estimate derived from the Surface Irrigation Soil Loss (SISL) model, The Trust ran simulations using three soil types that are common to the Mason Creek area and that represent the range of erodibility factors present in the area.

Table 3. Relevant characteristics of Mason Creek agricultural fields.

Field Characteristics	
Average Area	15.9 acres
Average Slope	1.45%
Dominant Soils	Vanderhoff-Badland complex (14.7%) Feltham-Quincy complex (14.4%) Garbutt silt loam (14.0%) Elijah-Vickery silt loam (10.7%) Bram silt loam (10.4%)
Soil Erodibility	
Average K Factor	0.32
Median K Factor	0.43

Parameters used in NTT BMP simulations

Soil types – Bram silt loam (K=0.49), Garbutt silt loam (K=0.43), Notus (K=0.20)
Field Area – 16 acres
Field Slope – 1.45%
Cropping System and Management[5]

Furrow/Flood Irrigation

- Irrigation Efficiency – 0.65
- Irrigation Frequency – 8 days

Sprinkler Irrigation

- Irrigation Efficiency – 0.90
- Irrigation Frequency – 8 days

[4] http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm
[5] Unless otherwise noted, NTT default parameters were used for all simulations.

Drip Irrigation

- Irrigation Efficiency – 0.95
- Irrigation Frequency – 8 days

No-Till

- NTT default "no-till" management regime

Cover Crop

- Species – Rye
- Planting Date – October 15
- Kill Date – April 1

Filter Strip

- Species – Indian Grass
- Strip to Upslope ratio – 2% (0.32 acres for 16 acre field)
- Strip Width – 30 feet
- Strip Slope ratio to upland – 1.0

The results from these simulations are described in Table 4. The fourth column in Table 4 summarizes the effectiveness rate identified through NTT scenario runs. The fifth column pulls the rates recommended by The Trust in Table 2. The last column summarizes the net difference between the NTT runs and The Trust's recommended rates.

Table 4. BMP sediment reduction efficiencies derived from NTT simulations. The more closely aligned the two percentages, the darker the shade of green. Lighter shades of green and yellow demonstrate a greater divide between The Trust's proposed revised effectiveness rates and the outputs from the NTT scenario runs.

Best Management Practice	Bram Silt Loam (K=0.49)		Garbutt Silt Loam (K=0.43)		Notus (K=0.20)		Mean (SD)	Estimated Efficiency	Difference
	Corn	Winter Wheat	Corn	Winter Wheat	Corn	Winter Wheat			
Furrow -> Sprinkler	77.7	79.4	78	79.3	76.1	77.4	78.0 (1.2)	90	12.0
Furrow -> Drip	99.6	NA	99.8	NA	99.9	NA	99.8 (0.2)	98	1.8
No-Till	73.1	74	73.7	73.7	72.2	99.1	77.6 (10.5)	70	7.6
Cover Crop	62	NA	62.6	NA	67.2	NA	63.9 (2.8)	60	3.9
Filter Strip	78.4	44.7	75.2	43.1	82.2	41	60.8 (19.7)	35	25.8
Cover Crop + Sprinkler	86.5	NA	86.2	NA	86.6	NA	86.4 (0.2)	94	7.6
Cover Crop + Filter Strip	90.1	NA	88.2	NA	90.1	NA	89.5 (1.1)	70	19.5
Cover Crop + No-Till	80.6	NA	92.5	NA	80.0	NA	84.4 (7.1)	83	1.4
Cover Crop + Sprinkler + Filter Strip	94.2	NA	97.7	NA	98.2	NA	96.7 (2.2)	95	1.7
Filter Strip + Sprinkler	94.7	86.4	94.8	87	97	84.1	90.7 (5.4)	96	5.3
Filter Strip + No-Till	92.1	80.2	92.3	82.6	93.7	87.2	88.0 (5.6)	77	11.0
Sprinkler + No-Till	93.6	92.1	94.2	92.3	90.7	92.8	92.6 (1.2)	95	2.4
Sprinkler + No-Till + Filter Strip	98.9	94.9	99	95.1	98.7	96.2	97.1 (2.0)	97	0.3

Results and Discussion

As documented in last column of Table 4, the results of the NTT simulations are generally well-aligned with the revised efficiency rates proposed by The Trust in Table 2. One practice—filter strips—showed a large discrepancy between the proposed Table 2 revised rate and the NTT simulation. To provide clarity on this issue, The Trust conducted additional research in order to determine if an additional rate revision was necessary. Based on this research, The Trust has concluded that the lower filter strip effectiveness rate stated in Table 2 is the most appropriate estimation, particularly in the context of a trading program with landowner participation lasting multiple years.

The Trust's conclusion is based on the following rationale:

- NTT estimates sediment loss on an annual basis, and does not account for the degradation and decreased efficacy of the filter system over multiple years.
- Degradation and decreased efficacy are a well-documented issue with filter strips. After the initial 1-2 years, accumulated sediment and soil-adsorbed phosphorus often reach concentrations high enough to inhibit additional storage, thereby greatly reducing the efficacy of the filter system (Dorioz et al., 2006). Unlike other pollutants, phosphorus undergoes no biogeochemical transformations that reduce the quantity stored within the buffer over time, therefore once the concentration reaches a high enough level the filter strip's phosphorus removal effectiveness becomes permanently impaired, and the area must be cultivated and re-seeded to restore its effectiveness (Dorioz et al., 2006; Grismer et al., 2006).
- Field studies and computer models both suggest that sediment reductions often do not equate to phosphorus reduction at the same ratio (2 lbs. phosphorus per ton of sediment) as can be assumed for other BMPs. This is due in part to the complexity of interactions and high variability due to the dependency on filter/grass type, soil type, field slope, chemical form of the pollutant in question, and uniformity of the runoff flowing into the filter, among other variables (Dorioz et al., 2006; Novotny, 2003; Tuppad, Kannan, et al., 2010). This issue is reflected in the large variance in efficiency rates documented in the literature review summarized in Table 1.

EVALUATION OF MULTIPLE BEST MANAGEMENT PRACTICES

The mechanisms through which different agricultural BMPs interact are often highly complex and poorly understood. Very little robust research exists documenting the effectiveness of multiple agricultural BMPs installed on the same farm. The information that does exist often struggles to explain how or why the effectiveness gains, or losses, were achieved. This lack of understanding is due in part to location-specific variability in weather, runoff, and drainage, combined with the unique biophysical attributes of each field. All of these factors make the interaction process extremely complex and difficult to predict. Because of this, the procedure for estimating the effectiveness of multiple BMPs for the purposes of nutrient trading must rely on a series of assumptions.

First, The Trust assumed that farmers know which management practice combinations are inherently incompatible (e.g., sprinkler irrigation and surge irrigation) and/or illogical (e.g., microirrigation and sediment basins) and will therefore avoid installing any of these combinations. It is understood that these combinations are not generally employed, therefore there is no reason to believe there would be interest in combining them for the purposes of generating trading credits.

Second, The Trust assumed that the effectiveness rate of some BMPs will be lower when stacked with other BMPs than when implemented alone, due in part to overlap in the mechanisms through which the two practices are reducing phosphorus losses. For example, both conservation tillage and cover crops reduce sediment loss by maintaining vegetative cover on the soil surface. In addition, the two practices are physically overlapping, and therefore acting on the same area of the field. Because of this spatial overlap, when they are combined, both contribute to phosphorus runoff reductions, but at an overall rate that is, on average, not likely to be substantially higher than that which could be achieved by each of the practices individually, depending on how, when, and where the practices are implemented. On the other hand, some BMPs may interact relatively independently if they do not overlap spatially and are structured differently. For example, a filter strip is installed on the edge of a field whereas as a BMP like cover cropping is installed on-field. These BMPs may complement each other without much spatial or functional redundancy.

In order to evaluate these assumptions, The Trust used the results of the NTT simulations outlined in Table 5 to compare the sediment reductions achieved by each BMP alone to reductions achieved by pairs of BMPs.[6] Physically overlapping BMP pairs were clustered separately from non-overlapping pairs to assess whether or not a substantial difference was found between these two classifications. Using data from Table 5, the "BMP 2 effectiveness reduction" was calculated for each BMP pairing by comparing the additional sediment reduction from the second BMP in the sequence to the sediment reduction achieved by the second BMP when implemented alone. Each pairing was evaluated twice – once for each possible sequence. The results of the evaluation are found in Tables 5 and 6.

[6] As stated on page 3 of this document, an efficiency rate has not been estimated for NRCS Practice 590 - Nutrient Management Planning. Therefore, this practice has been excluded from all modeling efforts. It is assumed that this practice will be implemented as a baseline or complementary BMP in conjunction with the other BMPs included in the assessment.

Table 5. Additional BMP effectiveness reductions from NTT simulations of physically overlapping BMPs.

Soil Name	Crop	BMP 1	BMP 1 Effectiveness	BMP 2	BMP 2 Effectiveness	Combined Effectiveness	BMP 2 Effectiveness Reduction
Bram Silt Loam	Corn	Cover Crop	62.0%	Sprinkler	77.7%	86.5%	17.0%
Bram Silt Loam	Corn	Sprinkler	77.7%	Cover Crop	62.0%	86.5%	36.4%
Garbutt Silt Loam	Corn	Cover Crop	62.6%	Sprinkler	78.0%	86.2%	19.1%
Garbutt Silt Loam	Corn	Sprinkler	78.0%	Cover Crop	62.6%	86.2%	40.5%
Notus	Corn	Cover Crop	67.2%	Sprinkler	76.1%	86.6%	22.3%
Notus	Corn	Sprinkler	76.1%	Cover Crop	67.2%	86.6%	34.6%
Bram Silt Loam	Corn	Sprinkler	77.7%	No Till	73.1%	93.6%	2.5%
Bram Silt Loam	Corn	No Till	73.1%	Sprinkler	77.7%	93.6%	1.9%
Bram Silt Loam	Wheat	Sprinkler	79.4%	No Till	74.0%	92.1%	16.7%
Bram Silt Loam	Wheat	No Till	74.0%	Sprinkler	79.4%	92.1%	12.3%
Garbutt Silt Loam	Corn	Sprinkler	78.0%	No Till	73.7%	94.2%	0.1%
Garbutt Silt Loam	Corn	No Till	73.7%	Sprinkler	78.0%	94.2%	0.1%
Garbutt Silt Loam	Wheat	Sprinkler	79.3%	No Till	73.7%	92.3%	14.8%
Garbutt Silt Loam	Wheat	No Till	73.7%	Sprinkler	79.3%	92.3%	10.8%
Notus	Corn	Sprinkler	76.1%	No Till	72.2%	90.7%	15.4%
Notus	Corn	No Till	72.2%	Sprinkler	76.1%	90.7%	12.6%
Notus	Wheat	Sprinkler	77.4%	No Till	99.1%	92.8%	31.2%
Bram Silt Loam	Corn	No Till	73.1%	Cover Crop	62.0%	80.6%	55.0%
Bram Silt Loam	Corn	Cover Crop	62.0%	No Till	73.1%	80.6%	33.0%
Garbutt Silt Loam	Corn	No Till	73.7%	Cover Crop	62.6%	92.5%	-14.2%
Garbutt Silt Loam	Corn	Cover Crop	62.6%	No Till	73.7%	92.5%	-8.5%
Notus	Corn	No Till	72.2%	Cover Crop	67.2%	80.0%	58.2%
Notus	Corn	Cover Crop	67.2%	No Till	72.2%	80.0%	45.9%
						Average Effectiveness Reduction	**19.9%**

Table 6. Additional BMP effectiveness reductions from NTT simulations of non-overlapping BMPs.

Soil Name	Crop	BMP 1	BMP 1 Effectiveness	BMP 2	BMP 2 Effectiveness	Combined Effectiveness	BMP 2 Effectiveness Reduction
Bram Silt Loam	Corn	Filter Strip	78.4%	Sprinkler	77.7%	94.7%	2.9%
Bram Silt Loam	Corn	Sprinkler	77.7%	Filter Strip	78.4%	94.7%	2.8%
Bram Silt Loam	Wheat	Filter Strip	44.7%	Sprinkler	79.4%	86.4%	5.0%
Bram Silt Loam	Wheat	Sprinkler	79.4%	Filter Strip	44.7%	86.4%	24.0%
Garbutt Silt Loam	Corn	Filter Strip	75.2%	Sprinkler	78.0%	94.8%	-1.3%
Garbutt Silt Loam	Corn	Sprinkler	78.0%	Filter Strip	75.2%	94.8%	-1.5%
Garbutt Silt Loam	Wheat	Filter Strip	43.1%	Sprinkler	79.3%	87.0%	2.7%
Garbutt Silt Loam	Wheat	Sprinkler	79.3%	Filter Strip	43.1%	87.0%	13.7%
Notus	Corn	Filter Strip	82.2%	Sprinkler	76.1%	97.0%	-9.3%
Notus	Corn	Sprinkler	76.1%	Filter Strip	82.2%	97.0%	-6.4%
Notus	Wheat	Filter Strip	41.0%	Sprinkler	77.4%	84.1%	5.6%
Notus	Wheat	Sprinkler	77.4%	Filter Strip	41.0%	84.1%	27.7%
Bram Silt Loam	Corn	Cover Crop	62.0%	Filter Strip	78.4%	90.1%	5.7%
Bram Silt Loam	Corn	Filter Strip	78.4%	Cover Crop	62.0%	90.1%	12.6%
Garbutt Silt Loam	Corn	Cover Crop	62.6%	Filter Strip	75.2%	88.2%	9.0%
Garbutt Silt Loam	Corn	Filter Strip	75.2%	Cover Crop	62.6%	88.2%	16.3%
Notus	Corn	Cover Crop	67.2%	Filter Strip	82.2%	90.1%	15.1%
Notus	Corn	Filter Strip	82.2%	Cover Crop	67.2%	90.1%	34.0%
Bram Silt Loam	Corn	Filter Strip	78.4%	No Till	73.1%	92.1%	13.2%
Bram Silt Loam	Corn	No Till	73.1%	Filter Strip	78.4%	92.1%	9.9%
Bram Silt Loam	Wheat	Filter Strip	44.7%	No Till	74.0%	80.2%	13.2%
Bram Silt Loam	Wheat	No Till	74.0%	Filter Strip	44.7%	80.2%	46.7%
Garbutt Silt Loam	Corn	Filter Strip	75.2%	No Till	73.7%	92.3%	6.4%
Garbutt Silt Loam	Corn	No Till	73.7%	Filter Strip	75.2%	92.3%	6.0%
Garbutt Silt Loam	Wheat	Filter Strip	43.1%	No Till	73.7%	82.6%	5.8%
Garbutt Silt Loam	Wheat	No Till	73.7%	Filter Strip	43.1%	82.6%	21.5%
Notus	Corn	Filter Strip	82.2%	No Till	72.2%	93.7%	10.5%
Notus	Corn	No Till	72.2%	Filter Strip	82.2%	93.7%	5.9%
Notus	Wheat	Filter Strip	41.0%	No Till	99.1%	87.2%	21.0%
						Average Effectiveness Reduction	**11.0%**

This evaluation, in part, highlights the site specificity inherent within each management practice in question. The effectiveness of each of these practices is a function of many variables, including soil type, field slope, and crop type; therefore, the field-level effectiveness of each BMP combination is likely to vary from one field to the next based on each field's specific characteristics. However, based on this evaluation The Trust recommends a two-part process for assessing the combined effectiveness of multiple BMPs implemented on a single field. Where practices spatially and functionally overlap (e.g., cover crop and conservation tillage), The Trust recommends a 20 percent discount rate for each additional BMP implemented. Where practices are spatially and functionally discrete, The Trust recommends an 11 percent discount rate for each additional BMP.

Although it is currently not possible to accurately account for all of the complexities of BMP interaction, these discount rates will acknowledge the improvement in phosphorus runoff reduction that is likely achieved by implementing multiple BMPs, while remaining conservative enough to avoid overestimation and reflect the diminishing returns that are likely to be seen with the employment of each additional practice.

The equation below describes how these discount rates are applied in the calculation of the overall effectiveness rate of multiple BMPs[7].

Equation 1a: Overlapping BMPs[8]

$$E_{1+2} = E_1 + 0.8E_2(1 - E_1)$$

Where,

E_{1+2}= Combined effectiveness of BMPs #1 and #2
E_1 = Effectiveness rate of BMP #1 (the more efficient of the two BMPs)
E_2 = Effectiveness rate of BMP #2

Equation 1b: Non-overlapping BMPs

$$E_{1+2} = E_1 + 0.89E_2(1 - E_1)$$

Where,

E_{1+2}= Combined effectiveness of BMPs #1 and #2
E_1 = Effectiveness rate of BMP #1 (the more efficient of the two BMPs)
E_2 = Effectiveness rate of BMP #2

Example 1: Sprinkler Upgrade and Cover Crop

E_1 = sprinkler efficiency rate = 90%

E_2 = cover crop efficiency rate = 60%

Because the two BMPs in question overlap, Equation 1a is used.

[7] Note: the more efficient of the two BMPs being implemented should be labeled "BMP#1"

[8] Physically overlapping BMP pairs are those that include any combination of the following: cover crop, strip or no-till, sprinkler upgrade, microirrigation upgrade, polyacrylamide, surge irrigation, or straw in furrows.

$$E_{1+2} = E_1 + 0.8E_2(1 - E_1)$$
$$= 0.9 + 0.8 * 0.6(1 - 0.9)$$
$$= 0.95\ or\ \mathbf{95}\%$$

Example 2: No-till and Filter Strip

E_1 = No till efficiency rate = 70%

E_2 = Filter strip efficiency rate = 35%

Because the two BMPs in question do not overlap, Equation 1b is used.

$$E_{1+2} = E_1 + 0.89E_2(1 - E_1)$$
$$= 0.7 + 0.89 * 0.35(1 - 0.7)$$
$$= 0.79\ or\ \mathbf{79}\%$$

The effectiveness of additional BMPs can be calculated using the same equation structure. For example, if the grower in Example 1 above also chooses switch to conservation tillage (effectiveness rate = 70%):

E_{1+2} = 95%

E_3 = 70%

$$E_{1+2+3} = E_{1+2} + 0.8E_3(1 - E_{1+2})$$
$$= 0.95 + 0.8 * 0.7(1 - 0.95)$$
$$= 0.98\ or\ \mathbf{98}\%$$

Using this method, the overall effectiveness values for BMP combinations have been calculated and included in Table 7.

Table 7. Combined effectiveness of multiple BMPs.

	Polyacrylamide	Sprinkler Irrigation	Microirrigation	Tailwater Recovery	Straw in Furrows	Strip-Till or No-Till	Sediment Basin, Field Scale	Sediment Basin, Watershed Scale	Underground Outlet, years 1-2	Underground Outlet, after year	Surge Irrigation	Constructed Wetland	Cover Crop	Filter Strip
(alone)	80	90	98	95	65	70	65	50	70	40	45	75	60	35
Polyacrylamide		96	na	99	90	91	85	89	92	87	87	81	90	86
Sprinkler Irrigation			na	99	95	96	96	94	96	94	na	97	95	93
Microirrigation				na	na	na	na	na	na	na	na	na	na	99
Tailwater Recovery					98	98	98	97	98	97	97	98	98	97
Straw in Furrows						86	85	81	87	77	78	89	82	76
Strip-Till or No-Till							87	77	89	81	81	91	84	79
Sediment Basin, Field Scale								na	87	97	97	na	84	76
Sediment Basin, Watershed Scale									83	68	70	na	78	66
Underground Outlet, years 1-2										na	82	91	86	79
Underground Outlet, after year											65	84	74	59
Surge Irrigation												80	74	62
Constructed Wetland													88	83
Cover Crop														55

Task 2: Hydrologic Connection Analysis

The Lower Boise River and its tributaries are extensively managed to support agricultural production in the subbasin. This management includes an extensive network of canals and drains that deliver and remove irrigation water. The hydrology of this network impacts the movement of water through the Lower Boise River watershed. In the current LBTF, different agricultural fields receive different site location ratios based on their hydrologic connection to return drains.[9] These location ratios are designed to account for the movement of irrigation return flows in the watershed and to ensure that calculated edge-of-field reductions from BMPs are properly adjusted to account for the water quality benefits that are likely to accrue to the Lower Boise River. The goal of this hydrologic connection analysis was to evaluate drainage patterns in the Lower Boise River watershed, and to describe additional options for accounting for this dynamic.

ANALYSIS APPROACH

The Trust began the hydrologic connection analysis by evaluating the NHDplus (EPA & USGS, 2012) dataset. The dataset includes flowlines that represent natural features, creeks, rivers, sloughs, and streams, as well as manmade features, including canals, ditches, drains, laterals, and other artificial paths. While the NHDplus flowlines are extensive, they do not capture all of the manmade water delivery and drainage ways in the Lower Boise subbasin. The complex system of irrigation canals and agricultural return drains dictates how water moves through the subbasin and the resulting impact on water quality.

In order to evaluation hydrologic connections in the Lower Boise subbasin, The Trust employed two analysis approaches, both based on flow accumulation methods described below.

Flow Accumulation Methods

The Trust evaluated surface drainage patterns in the Lower Boise subbasin using the available 10-meter digital elevation model (DEM) (Gesch, 2007) clipped to the Lower Boise subbasin. Using the DEM and ArcGIS tool, The Trust determined the direction of water flow across the landscape. The flow direction is calculated based on elevation and the results are combined to identify the direction of water flow across the landscape, delineating drainage patterns. The specific GIS steps to delineate drainage patterns are:

1. Clip the 10-meter DEM to the Lower Boise subbasin.
2. Fill sinks in the DEM using the 'Fill' tool (Spatial Analyst>Hydrology>Fill).
3. Create flow direction raster using 'Flow Direction' tool (Spatial Analyst>Hydrology>Flow Direction).
4. Create Flow Accumulation raster using 'Flow Accumulation' tool (Spatial Analyst>Hydrology>Flow Accumulation).
5. Display the Flow Accumulation based on 0.5 Standard Deviations. Visually inspect to determine cutoff value for pixels to include in the flowlines (4000 in this case).

The flow accumulation raster identifies the drainage patterns across the landscape. To evaluate drainage patterns in the Lower Boise subbasin, The Trust conducted two different analyses. In the

[9] Drainage Delivery Ratios and Site Location Factors are presented on pages 12-13 of the Lower Boise River Effluent Trading Demonstration Project document (Ross & Associates, 2000).

first, The Trust incorporated flow accumulation data with the ongoing drain delineation work being conducted by Idaho DEQ to evaluate hydrologic connections. In the second analysis, The Trust expanded the NHDplus drainage network by using the flow accumulation data to delineate additional flowlines in the subbasin.

Agricultural Field Outlet Mapping and Proximity Methods

While the flow accumulation raster identifies the drainage patterns across the landscape, it also identifies drainage patterns on each agricultural field. The Trust used this information to identify the drainage point on each delineated agricultural field within the Lower Boise subbasin. This point can be thought of as the 'outlet' of the agricultural field, the point to which water on the field drains. Given the resolution of the DEM (10 meters), this point may not correspond to the exact outlet point on each field, however, it does provide an understanding of the direction of flow on a field. Understanding the direction of flow on a field allowed The Trust to identify which return drain a particular field is likely draining to.

In a separate exercise, staff at Idaho DEQ have developed a GIS layer that delineates irrigation canals, creeks, and drains in the Treasure Valley, including: large delivery canals, small delivery canals, large drains, small drains, feeders, creeks, intermittent creeks, and rivers (H. Stone, personal communication, June 4, 2015). Idaho DEQ digitized these lines using available imagery and they include a level of detail not currently captured by another geospatial dataset. The Trust combined the results of the drainage pattern analysis with the canal and drain information from Idaho DEQ to evaluate the connectivity of agricultural fields and drains.

The Trust evaluated the proximity of the field drainage outlets described above to the canals and drains delineated by Idaho DEQ. To evaluate proximity, The Trust used the ArcGIS 'snap' tool (Editing>Snap) to 'snap' each field drainage outlet point to the nearest canal, creek, or drain delineated by Idaho DEQ using a tolerance of 500 meters. The Trust assumed that most return ditches would not carry runoff further than the width of two agricultural fields. Consequently, The Trust selected the 500 meter distance as it represents a value that is less than the width of two typical fields in the Lower Boise subbasin. The canal and drain dataset includes an extensive network of small delivery canals. For the purposes on this analysis, The Trust assumed that agricultural runoff was not draining to these small delivery canals. As such, these features were excluded from the proximity analysis. In the final output, each agricultural field is associated with a specific canal, creek, or drain.

Flowline Delineation and Buffering Methods

The Trust conducted a second, complementary analysis to support the hydrologic connectivity assessment. Using the flow accumulation raster, The Trust delineated additional drainage paths that are not captured in the NHDplus dataset. These drainage paths represent areas of high flow accumulation based on the elevation data and are represented as flowlines (Figure 1). The specific GIS steps to flowline delineation are:

1. Create a flow raster using a conditional statement on the flow accumulation raster. Code all pixels with values greater than 4000 as '1', and all pixels with values less than 4000 as 'no data' (Con("flow accumulation" > 4000, 1, " ")).

2. Convert the flow raster to polygon using 'Raster to Polyline' tool (Conversion Tools>From Raster>Raster to Polyline) to create flowlines.
3. Smooth flowlines using 'Smooth Line' tool (Cartography>Generalization>Smooth Line) – Smoothing Tolerance set to 200m, Smoothing Algorithm set to 'Paek'(Polynomial Approximation with Exponential Kernel).

The delineated flowlines are shown in Figure 1 in red. The flowlines capture the drainage patterns represented by the NHDplus lines (green) and additional drainage patterns not previously captured. These delineated flowlines illustrate the direction of water movement in the Lower Boise subbasin and can be used to provide an understanding of the connectivity of agricultural fields to the waterways (Figure 1). In order to estimate connectivity, The Trust assumed that runoff from a field "adjacent" to a drain is likely to reach that drain. To estimate adjacency, The Trust created four different buffers around each flowline: 10, 20, 50, and 100 meters. Using the 'Select Layer by Location' tool (Data Management>Select Layer by Location), every agricultural field that intersected with a buffer was selected to determine connectivity at the differing buffer widths. These selected fields were assumed to drain to the delineated flowlines.

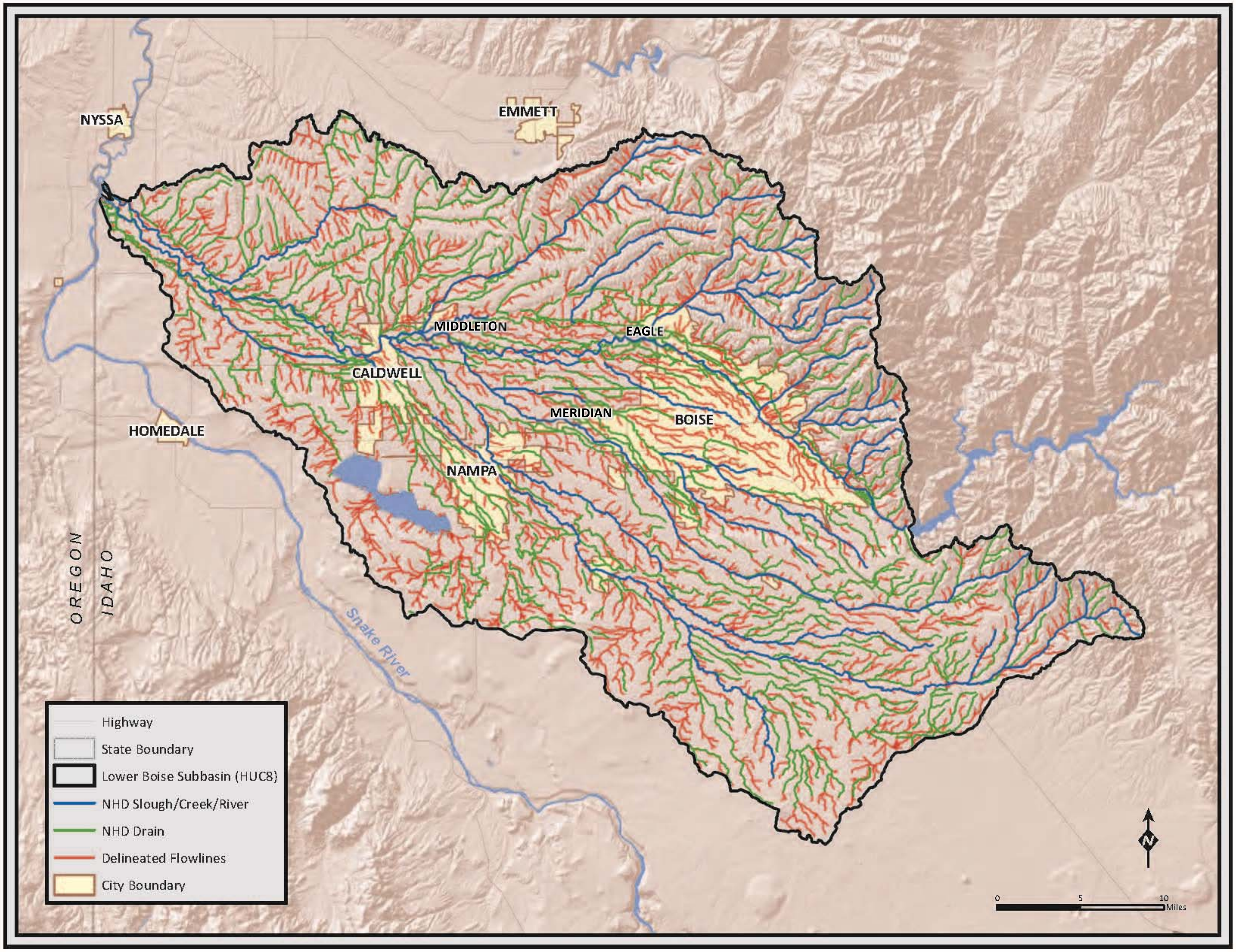


Figure 1. Drains in the Lower Boise River subbasin: originally identified in the NHDplus dataset (green), and additional delineated flowlines (red).

CONNECTIVITY RESULTS

The results of the two analysis approaches are described in the following two sections.

Agricultural Field Outlet Proximity Results

Using the first approach (the field outlet proximity analysis), 84.9% of agricultural fields (comprising 78.5% of studied acreage in the Lower Boise subbasin) were within 500 meters from a canal, creek, or drain. These proximity results are the result of a geospatial analysis and have not been verified on the ground. The results of this spatial analysis are described in Table 8.

Table 8. Agricultural fields and their associated acres with field outlets that are within 500 meters of a canal, creek, or drain.

		Number of Fields	% of Fields	Number of Acres	% of Acres
Not Connected to Lower Boise	**Irrigation Supply**				
	Named Irrigation Canals	1,174	11.2%	19,307	10.3%
	Large Irrigation Supplies	883	8.4%	13,919	7.4%
	Subtotal	***2,057***	***19.6%***	***33,226***	***17.7%***
Connected to Lower Boise	**Natural Waterbodies**				
	Creeks	432	4.1%	6,526	3.5%
	Intermittent Creek	199	1.9%	4,165	2.2%
	Lower Boise River	107	1.0%	1,894	1.0%
	Subtotal	***738***	***7.0%***	***12,585***	***6.7%***
	Drainage Systems				
	Large Drains	285	2.7%	5,466	2.9%
	Small Drains	5,809	55.5%	96,417	51.3%
	Subtotal	***6,094***	***58.2%***	***101,882***	***54.2%***
	Total	**8,889**	**84.9%**	**147,693**	**78.5%**

Using the field outlet proximity analysis, the field outlets for 1,582 of the 10,471 (15%) agricultural fields in the Lower Boise subbasin were greater than 500 meters from a canal, creek, or drain. For the purposes of this analysis, The Trust assumed that these fields are not directly connected to conveyances that will connect directly to the Lower Boise River. These fields are not included in Table 8.

The results of the field outlet proximity analysis (Table 8) indicate that 19.6% of the fields in the Lower Boise subbasin are draining directly to an irrigation canal. This corresponds to 17.7% of the acreage (33,226 acres). Agricultural runoff that flows into an irrigation canal will likely be reapplied to another field and may not reach the Lower Boise River. As a result, The Trust also categorized these fields as not directly connected to the Lower Boise River.

After extracting the 15% of agricultural fields that are greater than 500 meters from a canal, creek or drain, and extracting the 19.6% of fields that are within 500 meters of an irrigation canal, The Trust identified the remaining fields as those likely to have a direct connection to the Lower Boise River. These are the fields that drain to natural waterbodies (creeks and rivers) or to large or small drains. These connected fields represent 65.2% of the fields (114,467 acres).

Flowline Delineation and Buffering Results

The Trust employed the second approach (the flowline analysis approach described above) to support the results of the field outlet proximity analysis. Using the delineated flowline buffers and agricultural fields, The Trust evaluated four different buffer widths to assess connectivity. Using the smallest buffer width (10 meters), approximately 43% of the delineated agricultural fields were within 10 meters of the delineated flowlines, which corresponds to approximately 106,000 acres, or 56%, of the irrigated acreage. A larger number of fields and acreage were found to intersect with the largest delineated flowline buffer width (100 meters). Approximately 68% of the agricultural fields, which corresponds to approximately 144,000 acres, or 77%, of the irrigated agriculture acres, were within 100 meters of a delineated flowline. The number of fields and total acres within each delineated flowline buffer width are summarized in Table 9.

Table 9. Agricultural fields and their associated acreage that intersect with different flowline buffer widths.

Buffer	Number of Fields	% of Fields	Acres	% of Acres
10m	4,498	43%	105,578	56%
20m	5,028	48%	113,945	61%
50m	6,089	58%	129,567	69%
100m	7,135	68%	144,496	77%
Total	**10,471**		**188,051**	

The Trust evaluated the distance between field edges and the delineated flowlines in the subbasin. In most cases, the edge of each field was set back from the flowline. The Trust measured the distance between the edge of a field and the adjacent flowline for a subset of the fields in the subbasin. The Trust found that on average, the distance was approximately 50 meters. As a result, The Trust expects that 50 meters is likely the most appropriate buffer width for this analysis.

Results Comparison

The Trust compared the results of the two approaches and found that while the approaches employed different methods, the results were within a range relevant to the connectivity evaluation. The results of the field outlet proximity analysis indicate that 65.2% of the fields are connected to the Lower Boise River, while the 50 meter flowline buffer results indicate that 58% of the fields are connected. The connected acreage results, however, were reversed. The results of the field outlet proximity analysis indicate that 114,467 acres are connected to the Lower Boise River, while the 50 meter flowline buffer results suggest that a greater acreage, 129,567 acres, are connected to the Lower Boise River. While the results differ, the difference in connected acreage represents variability of 8% compared to the total acreage in the subbasin.

LIMITATIONS

This analysis provides insight into the extent of hydrologic connectivity in the Lower Boise subbasin; however, The Trust has identified several limitations worth highlighting. When using imagery and digital elevation models, any analysis is limited to surface assessments of water movement. If water were to flow below ground, for example, through a subsurface pipe, this feature would not be captured in a digital elevation model and would be difficult to identify through imagery. As such, these subsurface connections were likely not captured by this analysis and not incorporated into the delineated flowline drainage network.

The reuse of irrigation water is common in the Lower Boise River subbasin. Irrigation water reuse was not explicitly identified in this analysis. The hydrologic connection analysis was limited to a remote, geospatial assessment of proximity as an indicator of hydrologic connection. As a result, the reuse of irrigation water was not directly included in the analysis using on-the-ground information. Agricultural drains that are diverted and re-applied were not identified in this analysis.

In addition, it is possible that some drains may not be captured by either of the analysis approaches. In these cases, agricultural fields adjacent to these un-delineated drains would have been classified as un-connected, regardless of the actual drainage patterns.

OPTIONS FOR CONSIDERING HYDROLOGIC CONNECTIVITY

The results of this analysis emphasize that the Lower Boise River subbasin is a complex and highly connected system. Due to the complexity of the system, treatment of hydrological connectivity as an eligibility requirement could simplify the credit calculation process, while providing a clear and defensible methodology for ensuring that BMPs result in the expected water quality benefits to the Lower Boise River. In the absence of recent, high-resolution elevation data (e.g., LiDAR), or site-specific information, it is difficult to ascertain precisely where a field drains to. However, simply because a field is not adjacent to a delineated drain does not mean that it is not connected to a conveyance that is directly connected to the Lower Boise River. If imagery and digital elevation models do not demonstrate connectivity, individual fields should be evaluated on a case-by-case basis to determine whether a connection does exist.

Since the SISL model captures estimated soil loss from a field, and not the sediment load delivered to the river, it is important to ensure that the modeled on-field sediment reductions associated with a BMP accrue as water quality benefits to the Lower Boise River. In other words, if a field is not connected hydrologically, the likelihood of BMP benefits accruing to the Lower Boise River is limited because the sediment load, and attached phosphorus, does not reach the river. If the LBTF were to include hydrologic connectivity as an eligibility requirement, The Trust estimates that 31% – 39% of the irrigated acres in the Lower Boise River subbasin could be excluded from a phosphorus trading program. Some hydrologically connected fields may not appear to be connected after assessing digital imagery, and others that appear hydrologically connected may not be. As such, site-by-site assessment of connectivity will be important.

Task 3: Model Evaluation

Multiple field-scale and watershed-scale water quality models exist as options for use in a water quality trading program. The Trust has evaluated multiple potential models and compared them to the currently approved SISL model. To support the model evaluation, The Trust selected the Mason Creek subwatershed as a case study area to compare SISL model results to measured phosphorus loads. This analysis complements a concurrent analysis being conducted by Willamette Partnership to evaluate the impact of different potential baseline BMPs in the Mason Creek subwatershed.

MASON CREEK SUBWATERSHED CASE STUDY

The goal of The Trust's modeling evaluation effort is to identify whether the SISL model is still a good model choice for the Lower Boise River subbasin. To facilitate the model evaluation, The Trust used the Mason Creek subwatershed as a case study area to compare model results to instream water quality data collected by the U.S. Geological Survey (USGS). There are minimal point source impacts to water quality in Mason Creek, meaning water quality is primarily driven by nonpoint source loads. This makes Mason Creek an ideal area to compare measured water quality data at the mouth and modeled current conditions.

Mason Creek Water Quality Data

As part of an extensive monitoring effort, the USGS collected continuous discharge, turbidity, and water temperature data at the mouth of Mason Creek. The data collection began in March 2011 and ended in March 2012 (Etheridge et al., 2014). Based on a strong observed relationship between total phosphorus and turbidity, USGS developed a regression model that predicts total phosphorus concentrations based on turbidity and seasonality ($R^2 = 0.75$, $p<0.01$, Etheridge et al., 2014). Using the total phosphorus regression equation and continuous discharge data at the mouth of Mason Creek from March 2011 to March 2012, USGS estimated the total phosphorus load during irrigation season to be 23.1 tons (46,200 lbs.). As part of the concurrent analysis, Willamette Partnership worked with USGS to determine the load of total phosphorus that could be attributable to nonpoint sources during irrigation season. Based on the water quality data, Willamette Partnership and USGS estimated the total phosphorus load from nonpoint sources in Mason Creek during the 2011 irrigation season was 36,975 pounds per year (90% CI, 21,254 - 61,459 pounds).

Mason Creek Phosphorus and Sediment Modeling

To evaluate the continued usefulness of the SISL model, The Trust modeled sediment and phosphorus loss at the field-level in the Mason Creek subwatershed. The SISL modeling approach used here is a landscape-level evaluation that incorporates multiple geospatial datasets to estimate sediment loss at an individual farm field. To complete the comparison to the measured data, Mason Creek modeling was limited to data from 2011. A complete description of the SISL modeling approach is documented in the Water Quality Improvement Potential Evaluation Section of this document (Task 4).

Modeling Assumptions and Scenarios

In this effort, The Trust conducted sediment modeling on a landscape-scale using geospatial datasets. Wherever possible, The Trust identified specific characteristics at the field-level; however, not all characteristics can be identified remotely. For example, some agricultural practices can be identified in imagery (e.g., sprinkler systems), but many cannot be readily identified (e.g., tillage practices). To complete the Mason Creek modeling effort, The Trust developed seven different on-field scenarios and modeled them using SISL to develop an understanding of potential nonpoint sediment loading in the subwatershed. Combined, the results from these SISL modeling scenarios can be used to build a realistic range of potential sediment and phosphorus loading from surface irrigated fields in the Mason Creek subwatershed.

Using this generalized, landscape approach to modeling sediment loss from surface irrigated fields, The Trust's base SISL modeling scenario assumed that conventional agricultural practices were being implemented on all fields in the subwatershed. In addition, the base scenario assumes that all fields are surface irrigated, unless a pressurized irrigation system (i.e., center pivot, wheel line, hand line) could be identified via available imagery. In this base scenario calculation, The Trust used all of the available geospatial data for each individual farm field (e.g., elevation, soils, and crop types) and assumed the following: conventional tillage practices, no irrigation water management, and no conservation practices actively being employed. For the purposes of this analysis, The Trust assumed that recruitment efforts would prioritize surface irrigated fields in order to target fields with the greatest uplift potential. Therefore, The Trust's modeling efforts focused solely on surface irrigated fields and excluded all fields with pressurized irrigation systems.

The Trust evaluated two base scenarios and five alternative scenarios.

Base Scenarios:

Mean Annual: the Base Soil Loss (BSL) values are selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2005, 2007 – 2014, and assumes a 'Medium' furrow end condition. This scenario assumes that only conventional practices are being employed on each field in the subwatershed and represents the mean sediment loss for all nine years.

2011 Crop Data: a single BSL value is selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2011, and assumes a 'Medium' furrow end condition. This scenario assumes that only conventional practices are being employed on each field in the subwatershed. The sediment loss value represents loading expected in 2011 only.

Alternative Scenarios:

2011 Crop Data & None End Condition: a single BSL value is selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2011, and assumes a 'None' furrow end condition. This scenario assumes that only conventional practices are being employed on each field in the subwatershed. The sediment loss value represents loading expected in 2011 only and better furrow end conditions.

2011 Crop Data & Fields Intersected with 50m Flowline Buffer: a single BSL value is selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2011, and assumes a 'Medium' furrow end condition. This scenario assumes that only conventional practices are being employed on each field in the subwatershed. Agricultural fields that are within a 50 meter buffer around the delineated flowlines (for more information see the Hydrologic Connection Analysis Section, Task 2). The sediment loss value represents loading expected in 2011 only from the agricultural fields adjacent to drains in the Mason Creek subwatershed.

2011 Crop Data & Field Outlet Proximity Results: a single BSL value is selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2011, and assumes a ‘Medium’ furrow end condition. This scenario assumes that only conventional practices are being employed on each field in the subwatershed. The agricultural fields with field drainage outlets that drain to agricultural return drains or to the creek (for more information see the Hydrologic Connection Analysis Section, Task 2). The fields that drain into agricultural drains that discharge directly into Ridenbaugh Canal were not included in this scenario. The sediment loss value represents loading expected in 2011 only from the agricultural fields that have a field drainage outlet that has been identified as flowing to a drain that reaches Mason Creek.

2011 Crop Data & Surge Irrigation: a single BSL value is selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2011, and assumes a ‘Medium’ furrow end condition. This scenario assumes that surge irrigation is applied on approximately half of the surface irrigated fields in the Mason Creek subwatershed (IP adjustment factor = 0.5 on approximately 7,900 acres). The specific fields were randomly selected and modeled with the different adjustment factor. The sediment loss value represents loading expected in 2011 only.

2011 Crop Data & Residue Management: a single BSL value is selected for each delineated field given the physical characteristics of the field (mean slope, soil erodibility), crops from 2011, and assumes a ‘Medium’ furrow end condition. This scenario assumes that residue management is implemented on approximately one quarter of the surface irrigated fields in the Mason Creek subwatershed (CP adjustment factor = 0.2 on approximately 4,000 acres). The specific fields were randomly selected and modeled with the different adjustment factor. The sediment loss value represents loading expected in 2011 only.

Modeling Results

The field-scale sediment and total phosphorus loading results for all seven scenarios are presented in Table 10.The results represent calculated loads from surface irrigated fields in the Mason Creek subwatershed using the SISL model.

Table 10. Comparison of the modeled sediment and total phosphorus loads from the delineated agricultural fields in the Mason Creek subwatershed. The total phosphorus loads in the last column assume that two pounds of total phosphorus are associated with each modeled ton of sediment.

Modeling Scenario		Scenario Description	Sediment Load (tons/year)	Total Phosphorus Load (pounds/year)
Base Scenarios				
1	**Mean Annual**	Incorporates crop data from 2005, 2007-2014	27,865	55,730
2	**2011 Crop Data**	Based on 2011 crop data only and conventional practices	34,025	68,051
Alternative Scenarios				
3	**2011 Crop Data & None End Condition**	Based on 2011 crop data only and BSL values selected assuming no convex end conditions on all fields	29,508	59,015
4	**2011 Crop Data & Fields Intersected with 50m Flowline Buffer**	Based on 2011 crop data and only those fields that intersect with the 50m drain buffer	22,173	44,346
5	**2011 Crop Data & Field Outlet Proximity Results**	Based on 2011 crop data and only those fields with a field outlet that drains into a drain or creek that reaches Mason Creek	20,736	41,472
6	**2011 Crop Data & Surge Irrigation**	Based on 2011 crop data, randomly selected approximately ½ of all fields and assumed they are using surge irrigation	26,352	52,704
7	**2011 Crop Data & Residue Management**	Based on 2011 crop data, randomly selected approximately ¼ of all fields and assumed they are implementing residue management	27,383	54,766

The 2011 Crop Data base scenario (1) suggests that approximately 34,000 tons of sediment were lost from surface irrigated fields in the Mason Creek subwatershed in 2011. Assuming 2 lbs. of total phosphorus are associated with each ton of sediment, this corresponds to a loss of approximately 56,000 lbs. of total phosphorus.

The modeled sediment loss for 2011 is substantially higher than the mean annual load (2) of approximately 28,000 tons. The crops planted on the surface irrigated fields in the subwatershed drive the differences between the two base scenario results. As illustrated in Figure 2, the percentage of acres growing permanent cover crops (e.g., alfalfa) in 2011 was approximately 41%—the lowest percentage in all nine years—while approximately 26% of the acreage was growing row crops (e.g., corn) in 2011—the highest percentage in all nine years. As a result of the increase in the acreage of more erosive crops and the decrease in the acreage of the less erosive crops, sediment loading in 2011 was one of the highest years of loading.

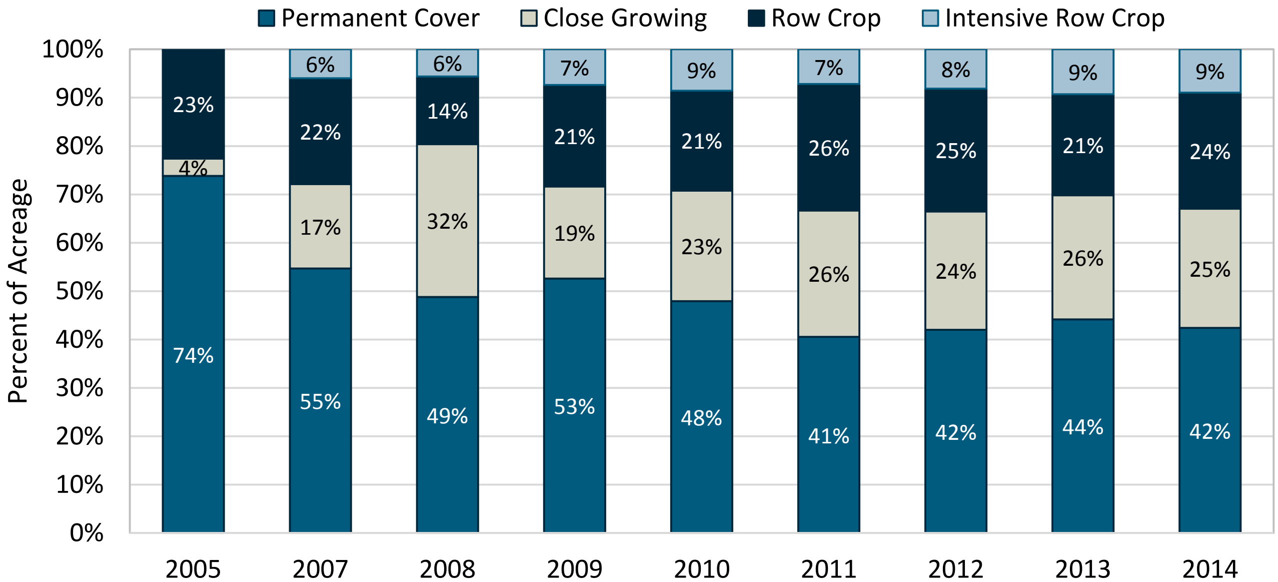


Figure 2. Distribution of crop types planted by year on the surface irrigated fields in the Mason Creek subwatershed. The figure highlights the annual variability in crops grown in the subwatershed, the characteristic that drives the variability in modeled sediment loads from year to year.

The furrow end condition can vary from field to field. Using the available remote sensing data, it is not possible to identify the furrow end conditions on each field. Improved end conditions are reflected in the 2011 Crop Data & N End Condition scenario (3). In this scenario, approximately 29,500 tons of sediment and 59,000 lbs. of total phosphorus would be lost from fields in the subwatershed if all fields had high quality end conditions.

The 2011 Crop Data & Fields Intersected with 50m Flowline Buffer scenario (4) incorporates the findings of one approach from the Hydrologic Connection Analysis (Task 2). The sediment loss value represents loading expected in 2011 only from the agricultural fields adjacent to drains in the Mason Creek subwatershed. The fields within the 50 meter buffer of the delineated flowlines have modeled sediment loads of approximately 22,000 tons and a corresponding total phosphorus load of approximately 44,000 lbs.

2011 Crop Data & Field Outlet Proximity Results scenario (5) incorporates the findings of the second approach from the Hydrologic Connection Analysis (Task 2). The 2011 modeled sediment loading from the surface irrigated fields with a field outlet that is connected to a drain is 21,000 tones. This corresponds to a total phosphorus load of approximately 42,000 lbs.

While information about agricultural practices in the subbasin suggests that conservation practices are being implemented, it was not possible using remote sensing in this analysis to identify what, if any, BMPs are being applied at the farm field-level. The final two alternative scenarios were included to represent the inclusion of these practices in the Mason Creek subwatershed. The two BMP scenarios suggest that if surge irrigation or residue management were employed on fields in the subwatershed, the total phosphorus load lost from field would be approximately 13,285 to 15,347 lbs. less than the 2011 Crop Data base scenario (6 and 7).

Comparison of Measured and Modeled Results

The modeled total phosphorus loads from all seven scenarios are consistently greater than the measured total phosphorus load. They range from approximately 12 to 84% greater than the total phosphorus load measured in 2011 that is attributed to irrigation runoff.

The fact that the modeled loads are consistently larger than the measured loads is not unexpected. The SISL model is an empirically-based "edge-of-field" sediment loss model. The modeled values represent the surface irrigation induced sediment erosion that leaves the end of the field, not the load that reaches the mouth of Mason Creek. As seen in the Hydrologic Connection Assessment (Task 2), not all of the fields in the subbasin are connected to the Lower Boise River. Runoff from many of these fields does not reach a drain or a creek that flows to the mouth of Mason Creek.

Two of the scenarios presented in Table 10 (scenarios 4 and 5) incorporate the results from the Hydrologic Connection Analysis (Task 2). Using the flowline buffer results (scenario 4), a smaller total phosphorus load of 44,346 lbs. is modeled as connected to the mouth of Mason Creek: 7,371 lbs. or 19.9% greater than the measured load. Using the field outlet proximity results (scenario 5), a smaller total phosphorus load, 41,472 lbs. is modeled as connected to the mouth of Mason Creek: 4,497 lbs. or 12.2% more than the measured load.

While the inclusion of the Hydrologic Connection Analysis provides a more realistic assessment of which fields are contributing to the total phosphorus loads measured at the mouth of Mason Creek, it is also likely that some sediment, and its associated phosphorus, will settle out of the water during conveyance during the irrigation season. Based on the SISL modeling, this corresponds to a loss of 10.8% – 16.6% of the modeled total phosphorus load during conveyance.

The Trust compared the SISL model results and the 2 lbs. of total phosphorus per ton of sediment relationship with the measured water quality data. The comparison highlights that the modeled results provide a good estimate of the measured total phosphorus loads in 2011, particularly when combined with the results of the Hydrologic Connection Analysis, and when considering that some percentage of sediment will settle out of the water during conveyance to the mouth.

SISL Model Timeframe

The results of the Mason Creek case study suggest that the majority of the modeled total phosphorus load is lost during irrigation season and is captured by the USGS water quality data. The Willamette Partnership, in collaboration with Idaho DEQ, is currently completing a concurrent assessment to determine the most appropriate choice for credit life in the subbasin. This effort will conclude in summer 2015 with a credit life recommendation.

OTHER POTENTIAL FIELD-SCALE MODELS

Other field-scale water quality models could be used to estimate nutrient runoff from agricultural fields and uplift potential from BMP implementation. A variety of models exist, each with their own unique set of strengths, weaknesses, and limitations. In the context of nutrient trading, quantification of nutrient runoff and uplift potential is often done in the absence of high quality field-level data, due in part to the large number of fields being evaluated. This process, therefore, often involves a number of assumptions about the area in question. Because of this, models that are less data intensive and more generalizable are considered to be the most appropriate.

Figure 3. Tradeoffs of nutrient models of varying degrees of complexity (adapted from (Arabi, 2012)).

In addition to the SISL model outlined above, other models are available that could be considered for use in quantifying supply and uplift for the purpose of a nutrient trading program. The two models deemed by The Trust to be reasonable alternatives for this context are outlined below.

Nutrient Tracking Tool (NTT)

As described above, NTT is a web-based field model that compares agricultural management systems in order to calculate a change in nitrogen, phosphorus, sediment loss potential, and crop yield. Users can enter baseline and alternative management systems, which are then simulated and compared to produce a report showing the nitrogen, phosphorus, sediment loss potential, and crop yield difference between the two scenarios.[10] By adjusting parameters for management practices and structural changes, users can simulate the pollutant reductions achieved by a variety of agricultural BMPs. The estimates are derived from USDA's RUSLE2.

The benefits of NTT include its relative efficiency, user-friendliness, and cost-effectiveness. Users are able to simulate a variety of cultural and structural conservation practices quickly using NTT defaults and preset parameters, making the process less data-intensive than other nutrient modeling tools. In addition, because NTT is a USDA-developed tool that uses the Agricultural Policy Environmental eXtender (APEX) model, it is considered to be scientifically credible.

In recent months, USDA-NRCS has re-engaged with the development and refinement of NTT. Their efforts include outreach to users and other stakeholders in an attempt to better understand their needs, as well as additional research aimed at calibrating the model's accuracy for a variety of additional geographic areas.

While NTT is a useful tool for many applications relevant to nutrient trading, there are limitations to its applicability. The mechanisms through which agricultural BMPs improve water quality are highly complex, and while user-friendliness and low data intensity allow for users to run quick simulations, it also means much of the complexity that exists on a given agricultural field is not fully taken into account in the simulations. However, for coarse sediment loading estimates on a watershed or

[10] http://nn.tarleton.edu/NTTWebARS

subwatershed scale aimed at providing an estimated range of outcomes, The Trust believes that this is an acceptable tradeoff.

Most relevant to the Lower Boise nutrient trading program, NTT lacks the geographic relevancy of the SISL model. Because NTT has not yet been calibrated for Southern Idaho or similar geographies, The Trust believes that the SISL model currently provides more accurate estimates than NTT for the Lower Boise area.

Agricultural Policy/Environmental eXtender (APEX)

The APEX model, also developed by USDA, is a flexible and dynamic tool capable of simulating management and land use impacts for whole farms and small watershed. APEX functions on a daily time step and can simulate the impacts of various "alternative" management practices over short or long time periods. In addition to the sediment and nutrient components included in NTT, APEX has components for routing water, pesticides, and carbon fate.

Simulating management practices with APEX requires users to input detailed information about the management practices of the field in question. APEX is more data intensive than NTT or SISL, and contains additional parameters that allow for more robust estimates of runoff potential, assuming the user has all of the requisite data for the field in question. Although this likely improves the accuracy of the model's simulations, it also requires a level of familiarity with the specific farming operation that is only held by the landowner and/or farm manager. This makes the tool ideal for the in-depth assessment of a specific field, but time-intensive for the general assessment of an area or subwatershed. Because the coarse estimates used for nutrient trading programs often involve a variety of assumptions that are then simulated across a range of field types in order to estimate the range of achievable outcomes, the data-intensity of APEX can limit its usefulness in this context. The Trust believes that the SISL model currently provides a better balance between accuracy and usability than APEX for the Lower Boise area.

CONCLUSION

Overall, there are a limited number of water quality models that can be used model the water quality benefits from agricultural BMPs at the field-level in the Lower Boise River subbasin. In this evaluation, The Trust employed a case study area to compare measured total phosphorus load to modeled loads in the Mason Creek subwatershed. The results of the Mason Creek case study identified a close agreement between the measured and modeled results. Based on the available information and analysis, The Trust has concluded that the SISL model continues to be a good model choice for the Lower Boise River subbasin. In addition, the case study results also support the original framework assumption of 2 lbs. of total phosphorus per ton of sediment.

The Trust recognizes that an excellent opportunity exists in the Lower Boise to continue to refine and improve the modeling approach. The opportunity to collect additional water quality data exists as new BMP projects are implemented. The projects can be instrumented and monitored to better understand the water quality benefits of these improved agricultural practices.

Task 4: Water Quality Improvement Potential Evaluation

The water quality benefits produced by a BMP will vary from field to field depending on multiple factors, such as: crops, soil type, field slope, and irrigation. By understanding where BMPs can most effectively reduce phosphorus loading, certain farm fields or drainage areas can be prioritized for implementation. Using the available geospatial data, The Trust has calculated the current phosphorus loading from agricultural fields in the Lower Boise subbasin. Using the modeling results, The Trust evaluated the different phosphorus loading characteristics of the subwatersheds to determine where BMPs can be targeted to produce the greatest water quality improvements.

The Trust used the Surface Irrigation Soil Loss (SISL) model to estimate total phosphorus loading in the Lower Boise River subbasin. The following section provides an explanation of the main components of the SISL model, the information used to populate the model, and any relevant assumptions required to complete the modeling effort.

WATER QUALITY MODELING APPROACH

The Idaho Natural Resources Conservation Services (NRCS) developed the SISL model to estimate annual soil loss from surface irrigated fields in Southwestern Idaho (NRCS, 2003). The SISL model is an empirical model that was developed by the NRCS using over 200 field-years of data from southern Idaho. The form of the SISL model is similar to that of the Universal Soil Loss Equation (USLE). The model estimates the overall soil loss at the end of a furrow by multiplying a base soil loss value by other adjustment factors to reflect the on-field conditions. The model takes the following form:

$$SISL = BSL \times KA \times PC \times CP \times IP$$

where,

- SISL: Surface irrigation soil loss
- BSL: Base soil loss
- KA: Soil erodibility adjustment factor
- PC: Prior crop adjustment factor
- CP: Conservation practice adjustment factor
- IP: Irrigation management adjustment factor

The base soil loss (BSL) values vary depending on the type of modeled crop (close growing, intensive row crop, permanent cover, and row crop), field slope, field length, and the elevation difference between the end of the furrow and the bottom of the return drain. The base soil loss value also differs by the inflow irrigation type (feed ditch, gated pipe, and siphon tube). Using the 200 field-years of soil loss data from conventional management practices, the NRCS measured base soil loss values for each of the different scenarios. The other four adjustment factors combine to modify the estimated soil loss.

Physical Characteristics of Assessed Fields

The first step in the modeling effort was digitizing the boundaries of the irrigated fields in the Lower Boise River subbasin. The heads-up digitizing was done using ArcMap (ESRI, 2012) and recent orthoimagery of the study area. The on-field irrigation type (sprinkler or surface irrigation) was then classified for each delineated field by visually inspecting the image. Pressurized irrigation systems (e.g. center pivots) were identified from recent orthoimagery where possible.

In order to run the SISL model, the physical characteristics of the fields within the study area are required. For each irrigated field, the following characteristics were determined:

- → Soils present on each field
- → Mean slope of each field
- → Area of each field (calculated after field delineation)

Dominant Soil Type

Using the Analysis tools in ArcMap (ESRI, 2012) the delineated fields were intersected with the *Ada County, Idaho (ID001), Canyon Area, Idaho (ID665), Gem County Area, Idaho (ID660), and Payette County, Idaho (ID659)* soil layers (NRCS, 2013). The resulting layer contains the different soil types present on each irrigated field. In addition to the soil type, the K factors associated with each soil type were included in the layer. The resulting soil layer was then converted to a high-resolution raster layer, where the pixel value was the K factor value. The high-resolution raster layer (input value raster), delineated fields layer (feature zone data), and the Zonal Statistics as Table tool were used to determine the mean K factor (statistic type: Mean) on each irrigated field. The resulting table was then joined to the original delineated fields layer.

Mean Slope

The slope of the field is important for selecting the appropriate base soil loss value for the field. Using the Slope tool from the Spatial Analyst toolbox in ArcMap (ESRI, 212) and the 10-meter DEM from the National Elevation Dataset (NED) (Gesch, 2007), slopes were calculated in degrees for each raster cell. The resulting slope later was used to determine the slope characteristics for each. The slope raster layer (input value raster), delineated fields layer (feature zone data), and the Zonal Statistics as Table tool were used to calculate the descriptive statistics for slope (statistic type: All) on each irrigated field. The resulting table was then joined to the original delineated fields layer. The key statistics included: mean, maximum, minimum, and standard deviation.

Base Soil Loss

The base soil loss values reflect measured sediment erosion from conventional on-field practices. The physical characteristics of a field affect the amount of soil erosion. Base soil loss values take these physical characteristics into account along with the crop present on the field. Table 11 illustrates an example of how the base soil loss values vary by crop and by the physical characteristics of the field in the SISL model. Different base soil loss values were used throughout the assessment to reflect both the physical characteristics of the fields and the crops present on each field.

Table 11: Base soil loss (BSL) values for different crop types and the physical characteristics of the field from the SISL model. The physical characteristics vary by slope (<1%, 1-1.9%, 2-2.9%, or >3%), field slope shape (none, moderate, or severe convex ends), and field length (660 feet or 1320 feet). The values represent the base soil loss in tons/acre/year for a field irrigated with a gated pipe system. Similar tables also exist for two other surface irrigation types (feeder ditch and siphon tube). Adapted from NRCS (2003).

Crop Type	Field Length (ft)	< 1%			1 - 1.9%			2 - 2.9%			> 3%		
		N*	M	S	N	M	S	N	M	S	N	M	S
Permanent Cover	660	0	0	0	0.7	0.9	1.3	2.4	3.0	4.3	5.9	7.4	10.3
	1320	0	0	0	0.6	0.7	1.0	1.9	2.4	3.4	4.7	5.9	8.2
Close Growing	660	1.2	1.4	1.9	3.4	4.2	5.9	6.7	8.4	11.8	10.9	13.7	19.1
	1320	1.0	1.1	1.5	2.7	3.4	4.7	5.4	6.7	9.4	8.7	11.0	15.3
Row Crop	660	2.6	3.3	4.6	9.1	11.4	16.1	19.3	24.2	32.2	29.4	36.8	51.5
	1320	2.1	2.6	3.7	7.3	9.1	12.9	15.4	19.4	25.8	23.5	29.4	41.2
Intensive Row Crop	660	3.4	4.2	5.9	12.7	16.0	22.3	27.7	34.7	48.5	46.2	57.8	80.9
	1320	2.7	3.4	4.7	10.2	12.8	17.8	22.2	27.8	38.8	37.0	46.2	64.7

* N, M and S refer to (N)one, (M)oderate, and (S)evere convex ends

Examples of the crop types listed in Table 11 are:

Permanent Cover:	Alfalfa, pasture, grass
Close Grown:	Grains, peas
Row Crop:	Beans, corn
Intensive Row Crop:	Sugar beets, onions, potatoes

The furrow end condition varies from field to field, and no general condition is known for the Lower Boise area. In order to ensure that a conservative base soil loss value is selected, The Trust assumed medium (M) field end condition for all modeled fields (less than 6 inches from field level grade to the bottom of the tail water ditch).

Typical field lengths were measured from recent orthoimagery. Field lengths in the Lower Boise area are typically within the 660 to 1320 feet range, and often greater than 1320 feet. In order to continue with the conservative base soil loss selection, the field length was assumed to be 1320 feet for all fields. Since base soil loss values from longer fields are lower, this ensures a more conservative sediment loss estimate.

The SISL model includes three surface irrigation methods: feeder ditch, gated pipe, and siphon tube. All three of irrigation methods are currently employed in the Lower Boise, however, gated pipe and siphon tubes are the most common systems. For the purpose of this analysis, The Trust assumes that an equal distribution of gated pipe and siphon tube systems on the surface irrigated fields in the Lower Boise River subbasin. This assumption is reflected in the model by using the average of the two BSL values when selected a BSL value for an individual field.

Soil Erodibility Adjustment Factor (KA)

The soil erodibility adjustment factor (KA) is based on the soil erosion factor (K factor) from NRCS soil surveys (NRCS, 2003). The KA factor used in the SISL model is the NRCS K factor for the modeled soils, multiplied by 2.04 (NRCS, 2003). The appropriate K factors for the soil types present on each field was used in the analysis.

Prior Crop Adjustment Factor (PC)

The SISL model includes a prior crop adjustment factor (PC) to account for crop residue from the previous year's crop. High residue crops provide additional resistance to soil erosion. USDA crop data (USDA, 2005 and 2007-2014) were used to determine the crop type in the previous year, which informed the selection of the PC adjustment factor for that year. The PC adjustment factors for various crops are listed in Table 12.

Table 12: Prior crop (PC) adjustment factors used in the SISL model. Adapted from NRCS (2003).

Crop	PC Adjustment Factor
Pasture	0.65
Alfalfa	0.70
Mint	0.70
Alfalfa Seed	0.75
Small Grain – High Residue	0.75
Corn – High Residue	0.75
Corn Silage	0.85
Sugar Beets	1.00
Potatoes	1.00

Conservation Practice Adjustment Factor (CP)

Adjustment factors for conservation practices are incorporated into the SISL model. Any variation of conservation practices can be altered through the CP adjustment factor. No additional information was available to suggest if additional conservation practices were being implemented in the Lower Boise area. As a result, the Lower Boise sediment modeling assumes only conventional tillage is being implemented. The CP adjustment factors for various crops are listed in Table 13.

Table 13: Conservation practice (CP) adjustment factors used in the SISL model. Adapted from NRCS (2003).

Conservation Practice	CP Adjustment Factor
Nothing	1.00
Conventional Tillage	1.00
Residue Management	0.20
Residue Management - Seasonal	0.20
Residue Management - Mulch Till	0.15
Residue Management - No Till	0.10
PAM Full Season	0.50
Full Season - PAM alone	0.30
Full Season - PAM + Irrigation Water Mgt.	0.05
Full Season - PAM + Irrigation Water Mgt.+ Residue Mgt.	0.01
PAM Part Season	0.30
Part Season - PAM alone	0.50
Part Season - PAM + Irrigation Water Mgt.	0.20
Part Season - PAM + Irrigation Water Mgt.+ Residue Mgt.	0.05
Deep Tillage	0.50
Alfalfa Seed	0.35
Alfalfa Hay (more than one year in rotation)	0.20

Irrigation Management Adjustment Factor (IP)

Typical surface irrigation practices are reflected in the irrigation management adjustment factor (IP). The specific irrigation methods employed in the Lower Boise area are unknown. As a result, the assessment assumed that no additional irrigation management practices were used (IP = 1.0). Surge irrigation, however, is included in the lower bound modeling scenario. The IP adjustment factors for various crops are listed in Table 14.

Table 14: Irrigation Management (IP) adjustment factors used in the SISL model. Adapted from NRCS (2003).

Irrigation Management	IP Adjustment Factor
Nothing	1.0
High level Irrigation Water Mgt. w/o cutback	0.9
High level Irrigation Water Mgt. with cutback	0.7
Surge Irrigation	0.5

Crop Rotations

In order to determine typical crop rotations, USDA crop data were analyzed using ArcGIS to determine which crops were present in the Lower Boise area. At the time of the analysis, nine years of crop data were available (USDA, 2005 and 2007-2014). The available crop data were used to determine the dominant crop present on each delineated field for each year of data. The crop raster layer for each year (input value raster), delineated fields layer (feature zone data), and the Zonal Statistics as Table tool were used to determine the dominant crop type (statistic type: Majority) on each irrigated field for each year with crop data. The resulting nine tables were then joined to the original delineated fields layer.

Each crop type was then categorized using the appropriate SISL categories: Permanent Cover, Close Grown, Row Crop, and Intensive Row Crop. With these classifications, the crops present on each individual field in the Lower Boise area were used to model the expected sediment loss from each field, for each year of crop data. The crop type present on each field was used in conjunction with the physical characteristics of the field to select an appropriate base soil loss value for the field.

Calculated Sediment and Total Phosphorus Loading

Using the available geospatial information to populate the SISL model, The Trust calculated the expected sediment loss from surface irrigated fields in the Lower Boise subbasin. The Trust included the nine years of crop data in the analysis to calculate a mean annual load. Total phosphorus loads were calculated using the original two lbs. of total phosphorus per ton of sediment estimate. Furthermore, while The Trust's modeling effort was focused on phosphorus loading in the Lower Boise River, it should be noted that additional ecological benefits would also likely to be achieved as the result of the implementation of a water quality trading program. Reductions in runoff of other agricultural inputs, such as pesticides and nitrogen fertilizer, would also likely be achieved, as well as improved groundwater quality due to reductions in leaching of agricultural chemicals.

MODELING RESULTS

The results of the SISL modeling effort indicate that a large load of sediment is being lost due to surface irrigation in the Lower Boise River subbasin. Based on the available geospatial data, The Trust estimates that the annual sediment load from all surface irrigated fields in the subbasin is approximately 435,000 tons, which corresponds to approximately 3 tons per acre. Using the 2 lbs. of total phosphorus per ton of sediment relationship, this translates to a loss of approximately 6 lbs. of total phosphorus per acre.

The distribution of loading can be seen in Figure 4. Figure 4 highlights the distribution of total phosphorus loading by field in the subbasin. Fields that are a darker brown color have higher modeled total phosphorus loads, while those lighter in color are modeled as having minimal total phosphorus loads. Figure 5 illustrates the same modeling results, but aggregated by subwatershed. The darker colors illustrate the subwatersheds with the highest total phosphorus loading.

The Trust does not expect the entire modeled load to reach the Lower Boise River. The Hydrologic Connection Analysis (Task 2) emphasized that a number of fields in the subbasin are not directly connected to the river. The Trust incorporated the findings from Task 2 and found that approximately 40% of the modeled sediment and total phosphorus load is likely diverted before reaching the Lower Boise River. In addition, The Trust expects that some percentage of the phosphorus-attached sediment load will settle out of the water column before reaching the Lower Boise River.

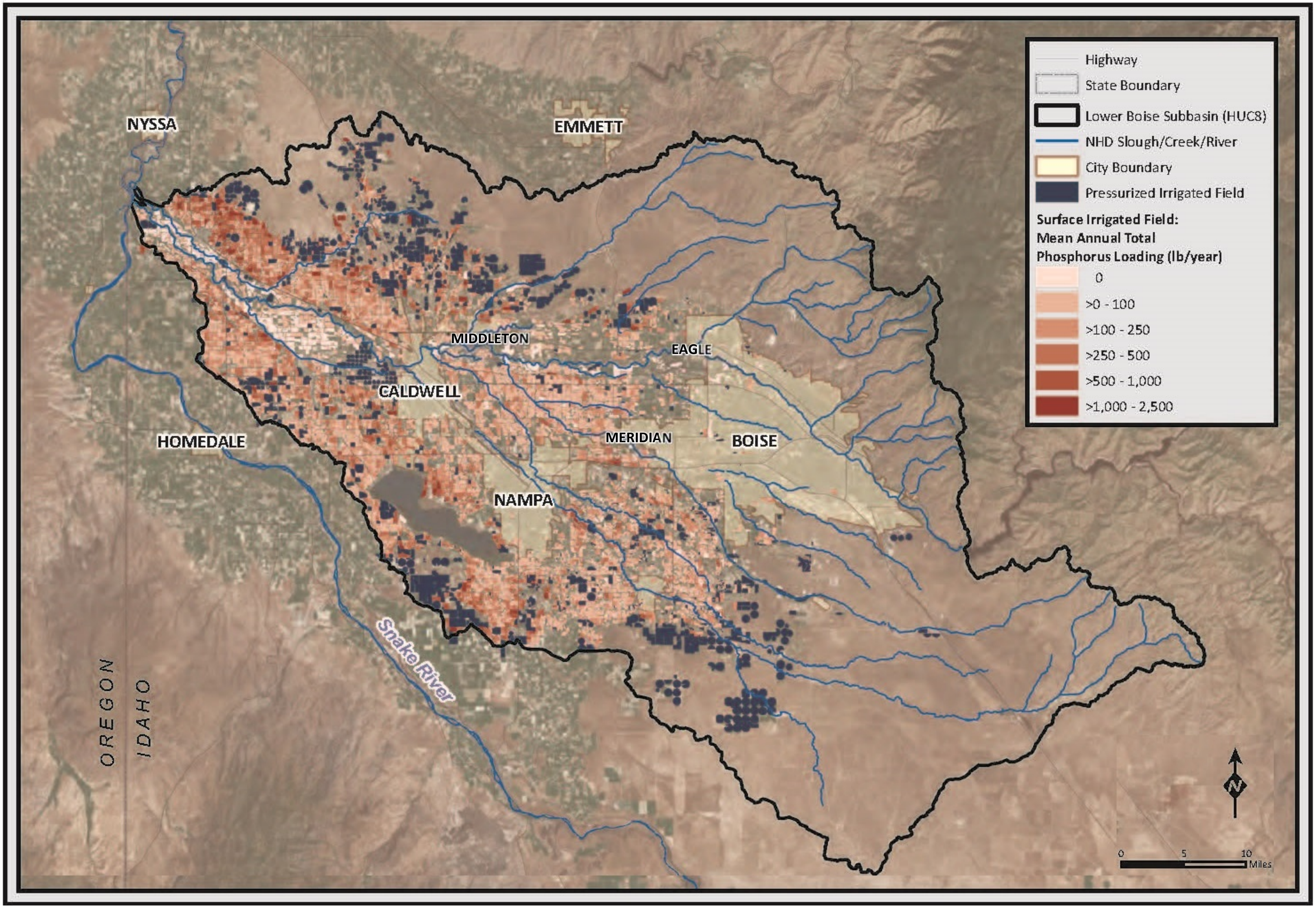
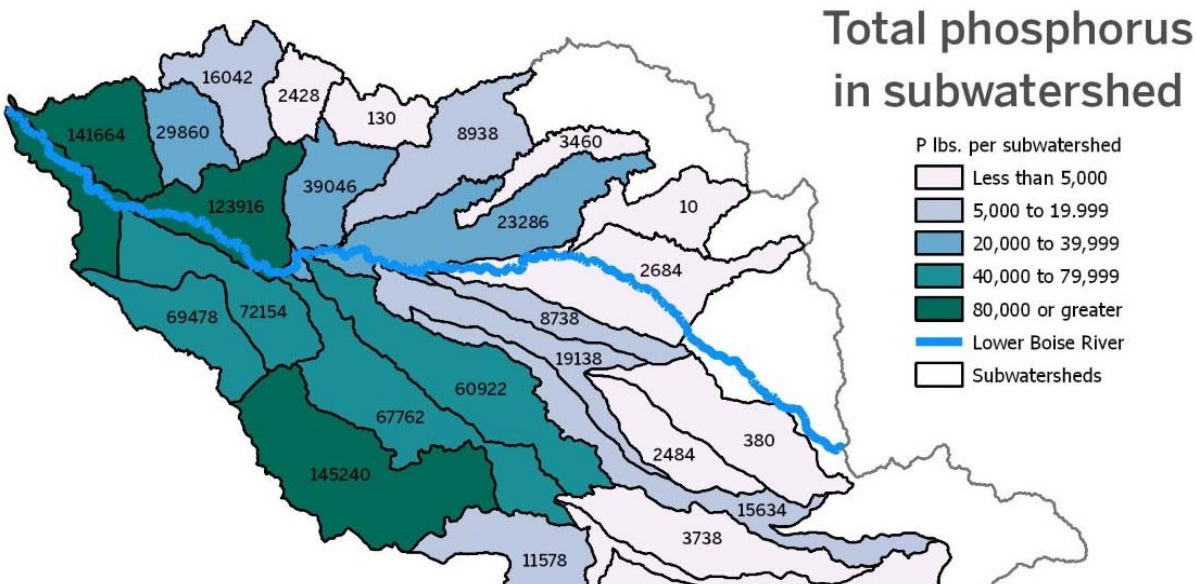
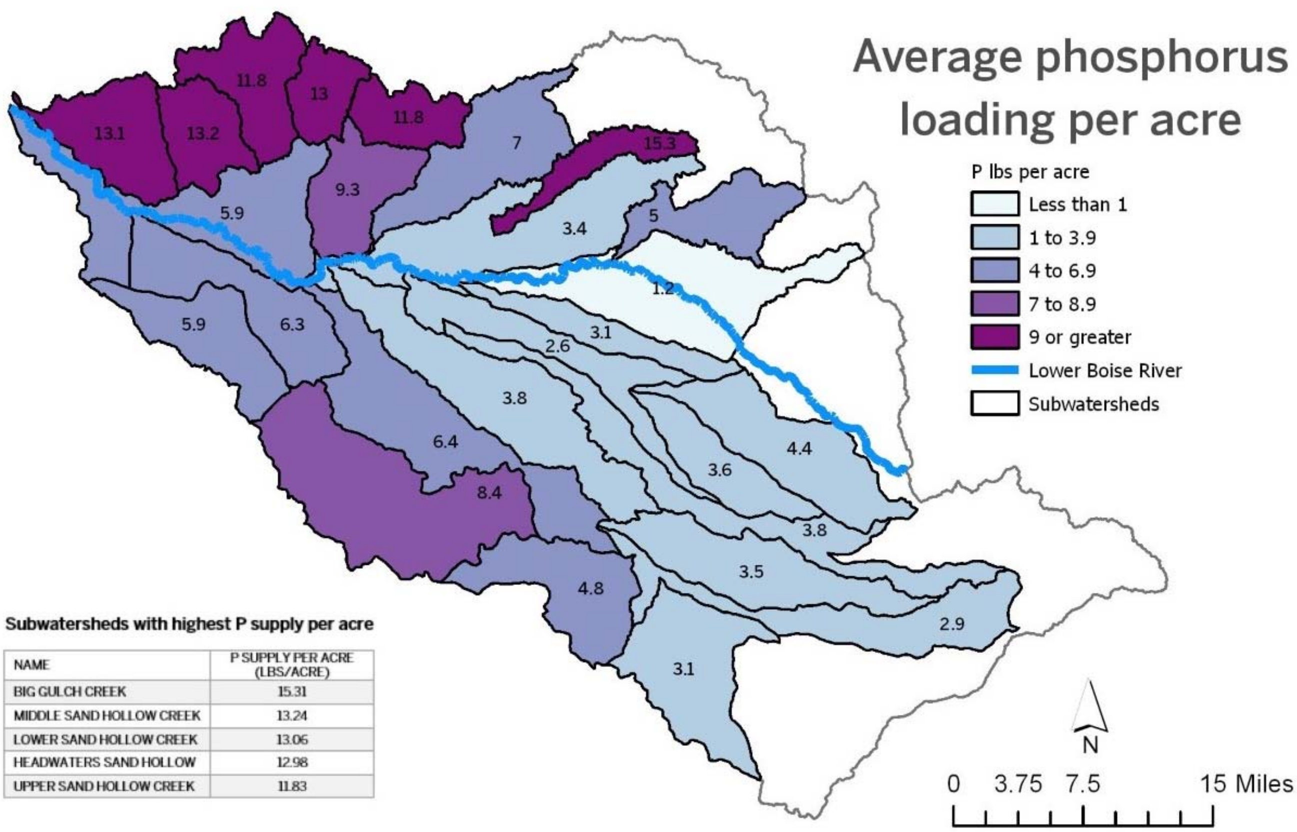


Figure 4. Modeled mean annual total phosphorus loading (lbs./year, from nine years of crop data) for all surface irrigated fields in the Lower Boise subbasin.



Subwatersheds with highest total P supply

NAME	TOTAL P SUPPLY (LBS)
COULEE DRAIN-LAKE LOWELL	145,240
LOWER SAND HOLLOW CREEK	141,664
OUTLET BOISE RIVER	123,916
DIXIE SLOUGH	72,154
LOW LINE CANAL	69,478



Subwatersheds with highest P supply per acre

NAME	P SUPPLY PER ACRE (LBS/ACRE)
BIG GULCH CREEK	15.31
MIDDLE SAND HOLLOW CREEK	13.24
LOWER SAND HOLLOW CREEK	13.06
HEADWATERS SAND HOLLOW	12.98
UPPER SAND HOLLOW CREEK	11.83

Figure 5. Phosphorus loading by HUC12 (subwatershed) from surface irrigated fields in the Lower Boise subbasin. Estimates are based on the SISL modeling methodology and data sources outlined on pp 35-40.

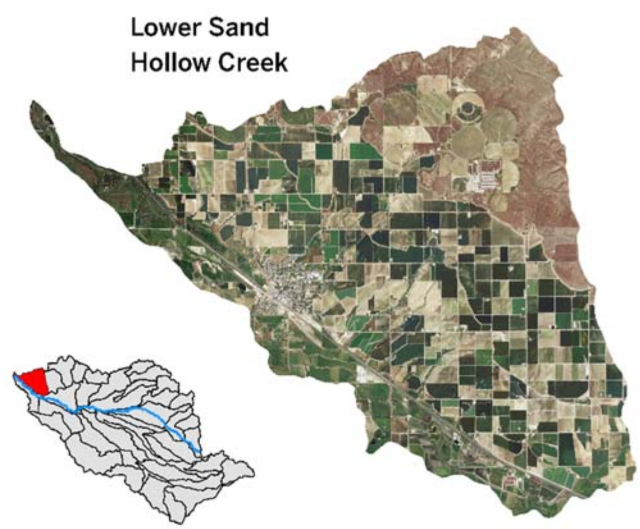
PRIORITIZATION OF CONSERVATION ACTIONS

In order to improve program efficiency and cost-effectiveness, agricultural conservation efforts in the Lower Boise watershed should focus on areas with the greatest potential for improvement. In the context of agricultural BMPs, effective subwatershed targeting could take into consideration the following criteria: 1) total supply of phosphorus in the subwatershed; 2) phosphorus supply per acre of agricultural land; 3) average farm size in the subwatershed; and 4) landowner willingness to participate. Ideally, the trading program would focus on areas with the largest total supply, the highest per acre supply, the largest average farm size, and the highest rate of landowner willingness to participate. Doing so would improve the efficiency of the trading program by reducing transaction costs and maximizing the achievable reductions per landowner contract.

Although actual targeting, particularly the assessment of landowner willingness to participate, would require additional on-the-ground evaluation of the local environment and context, a number of the criteria in question can be assessed using readily available data from The Trust's modeling efforts outlined earlier in this document. Utilizing these data, The Trust has highlighted two subwatersheds in the Lower Boise in order to illustrate how "high priority areas" could be identified for the targeting of agricultural BMPs.

Lower Sand Hollow Creek (HUC 170501140704)

Area (km²)	84
Total P supply (lbs.)	141,664
P supply per acre (lbs./acre)	13.06
Average field size	14.89



The Lower Sand Hollow Creek subwatershed is characterized by mostly surface irrigated agricultural fields. Directly adjacent to the Lower Boise River, Lower Sand Hollow Creek has among the highest average phosphorus loading per acre, as well as the second highest total phosphorus supply in the entire watershed. Although the average size of agricultural fields in the subwatershed is relatively small, the combination of high overall loading, high per acre loading, and close proximity to the Lower Boise River make Lower Sand Hollow Creek an ideal area in which to target agricultural conservation efforts.

Outlet Boise River (HUC 170501140803)

Area (km²)	161
Total P supply (lbs.)	123,916
P supply per acre (lbs./acre)	5.91
Average field size	18.24

The Boise River Outlet subwatershed also contains mostly surface irrigated agricultural fields. With the Lower Boise River bisecting this subwatershed, most fields in this area are a relatively short distance from the river. Although sprinkler irrigation is not uncommon here, many of the sprinkler irrigated fields are located further from the banks of the Lower Boise River, in the northeast corner of the subwatershed. In addition, the results of the Hydrologic Connection Analysis (Task 2) indicate that 78% of the surface irrigated acres are connected to the Lower Boise River. This subwatershed has among the highest total phosphorus loading of all subwatersheds in the Lower Boise subbasin and an average field size that is slightly larger than the subbasin average. Although the phosphorus loading per acre is lower than some subwatersheds in the area, its high total phosphorus supply and close proximity to the Lower Boise River make the Boise River Outlet subwatershed a high priority area for agricultural conservation efforts.

Summary

To make trading viable in the Lower Boise River, permittees and regulators need to know which land management actions will result in water quality improvements, and where such actions would be best focused. This report has synthesized the data sets not included in the TMDL process and offers scientific analysis that will help to inform the update of the Lower Boise River Trading Framework for total phosphorus. The data and analyses presented in this report are meant to support the ongoing efforts in the subbasin and provide a technical foundation that can be used for management decisions.

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