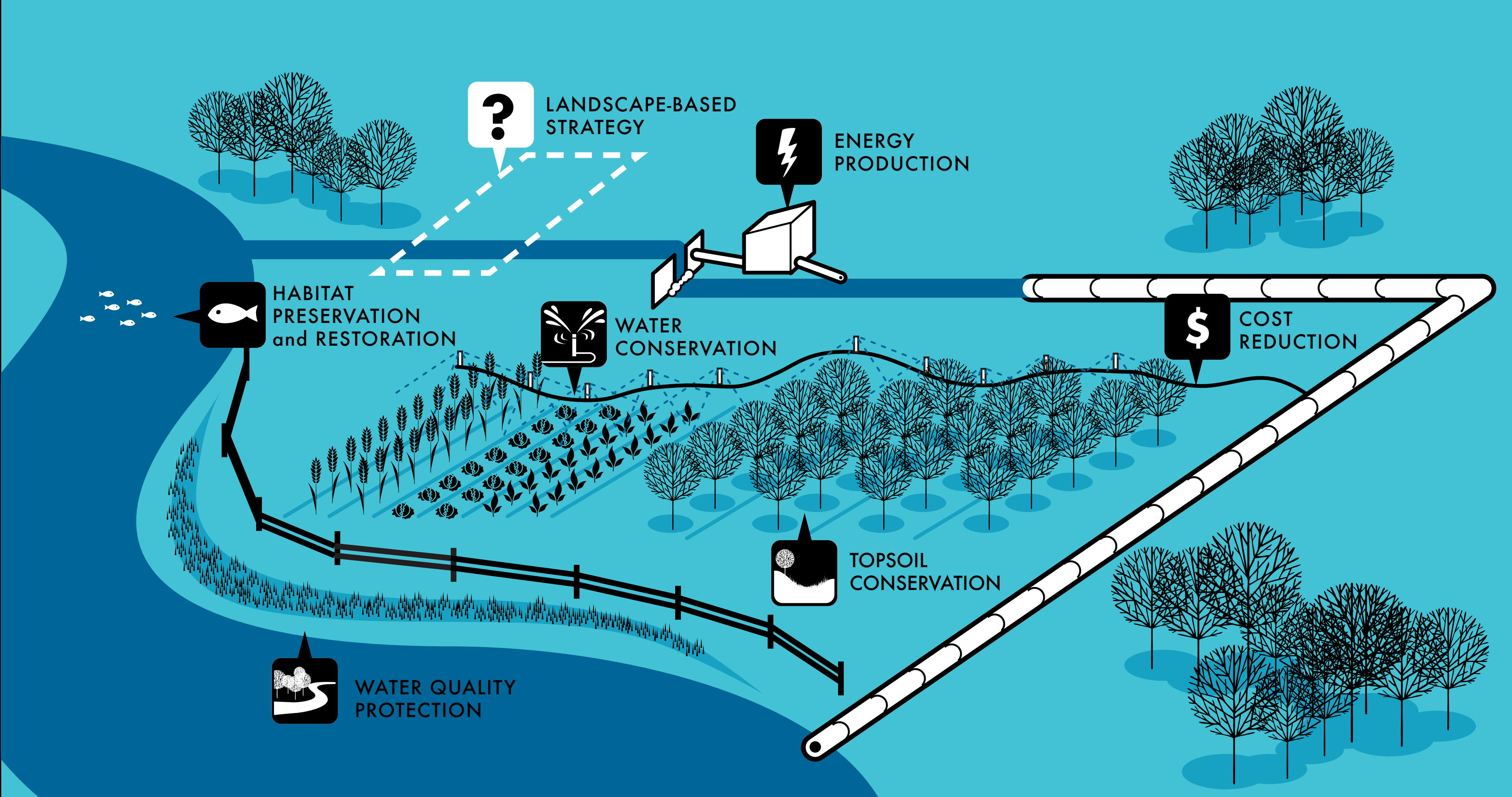


ENABLING SUSTAINABLE IRRIGATION

Determining the feasibility of landscape-based strategies for suspended sediment filtration in agricultural irrigation districts

Madeline B Carroll :: June 14, 2013

Submitted in partial fulfillment for the Master of Landscape Architecture, Department of Landscape Architecture, University of Oregon, and in partial fulfillment for the Master of Community and Regional Planning, Department of Planning, Public Policy and Management, University of Oregon.

ENABLING SUSTAINABLE IRRIGATION

Determining the feasibility of landscape-based strategies for suspended sediment filtration in agricultural irrigation districts

Madeline B Carroll :: June 14, 2013

Submitted in partial fulfillment for the Master of Landscape Architecture, Department of Landscape Architecture, University of Oregon, and in partial fulfillment for the Master of Community and Regional Planning, Department of Planning, Public Policy and Management, University of Oregon.

Masters Committee	Approval
David Hulse (Chair, MLA)	______________________
Roxi Thoren (Co-Chair, MLA)	______________________
Yitzhao Yang (Co-Chair, MCRP)	______________________

ABSTRACT

Problem

Fine soil particles (suspended sediment) in irrigation water can clog and damage irrigation equipment. Water-conserving and energy-saving strategies, like drip irrigation, low-flow sprinklers, and small-scale hydropower plants are particularly susceptible to damage, which hinders their broader adoption (Lamm, ESHA). The agricultural community is seeking a consistent, proactive sediment management strategy, at the district scale (Camp).

Research

This project develops and demonstrates a transferable method to determine whether landscape-based strategies might be feasible sediment filtration solutions for irrigation districts to field test. I conducted a review of academic studies, practitioner reports, and EPA best management practice recommendations to expand understanding of the problem.

Research products include:

A typology of built forms that remove sediment from water.

A typology of landscape-based strategies that employ those built forms

Strengths, weaknesses, opportunities, and threats (SWOT) analyses of three selected strategies: vegetated filters, compost filters, and constructed wetlands.

Based on these research products and decision-making theory, I developed a fast, easy, step-by-step method to identify sources of sediment and potential build sites for landscape-based strategies in the district; to rule out any of the three selected landscape-based strategies that would not feasibly function on each of the potential sites; and to estimate the implementation (build and maintain) costs of the remaining landscape-based strategies.

Results

I applied the method to the Farmers Irrigation District (FID) in Hood River, Oregon as a study site. I identified eight sources of sediment and nine potential build sites in the district, ruled out infeasible landscape-based strategies for each potential site, and found that implementation of the remaining potential strategies could be very or reasonably cost-effective.

Dedicated to Lynette Margaret Carroll,
whose stories of farm life taught me the incalculable value of agriculture,
and who found joy and music in every tree, flower, and bird she encountered.

Acknowledgements:
I owe an immense amount of gratitude to University of Oregon faculty members Dave Hulse, Yizhao Yang, Deni Ruggeri, Roxi Thoren, and Leo Yui for their expertise and undying encouragement.

A huge thank you to Farmers Irrigation District of Hood River staff Jerry Bryan and Jer Camarata, for initiating this project and providing invaluable input with style and humor. Thank you also to Brett Moore and June Brock for their help gathering data.

Thank you to Karen Johnson, for cheering me on and keeping me gainfully employed.

Thank you to Courtney Jellar, for her patient coaching.

Thank you to my parents, Claire and Devin Carroll, for their unconditional love and support.

And thank you to Ben, for believing in my ability to get it done, even when I had my doubts.

TABLE OF CONTENTS

LIST OF TABLES & FIGURES

INTRODUCTION

Project Summary

In winter of 2012 the Farmer's Irrigation District (FID) of Hood River contacted Professor David Hulse from the Department of Landscape Architecture at the University of Oregon in search of research support. They were exploring the idea of designing a constructed wetland to filter suspended sediment out of the district's diversion water. I was thrilled to be chosen for the project, and soon began collaboration with Jerry Bryan and Jer Camarata, my personable FID clients. *(See appendix A for more information about FID.)*

FID identified a potential build site adjacent to the district's main canal (the Farmers Canal) for their proposed constructed wetland. It became clear during our first site visit that a number of questions would need to be answered before the project could move forward: Where is suspended sediment entering the system? What size are the target sediment particles? Is a constructed wetland the best option? What other types of landscape-based strategies filter suspended sediment? How large would a landscape-based strategy need to be to process the sizable volume of water diverted by the district? How much would a landscape-based strategy cost to build and maintain?

We concluded that answering these questions was an essential step toward determining the feasibility of the project. With this goal in mind, I decided to develop a decision-making method to determine whether landscape-based strategies might be feasible sediment filtration solutions for irrigation districts to field test at identified sites. FID verified that a method of this type would be valuable to the district, and could be transferably valuable to other irrigation districts.

Method Development

With input from FID, I identified two key variables that might increase the transferable value of the method.

I. Cost and time effectiveness

The method should be fast, easy, and step-by-step. For the purpose of this project, I chose to define "fast," "easy," and "step-by-step" as follows.

Fast: The method is designed to be implemented in 30 days or less.

Easy: The method only requires data that most irrigation districts already have available, or that they can gather with their current staff, equipment, and expertise. Implementation of the method does not require complex training or specialized education.

Step-by-step: The method follows a simple, logical progression, developed to find an answer as early in the process as possible, with the least amount of work.

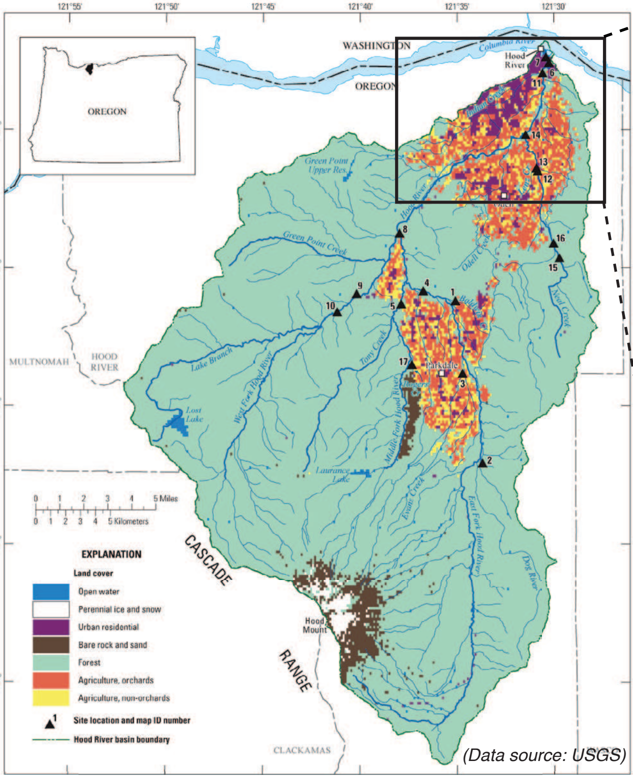
II. Both landscape-scale and site-scale analysis

The method should include steps that are applied at two different scales.

First, a high-level landscape-scale analysis to identify suspended sediment sources and potential build sites. At this scale, some landscape-based strategies might be ruled infeasible based on their estimated extents.

Second, a more detailed site-scale analysis to rule out infeasible landscape-based strategies for each potential site

HOOD RIVER WATERSHED



FARMERS IRRIGATION DISTRICT OF HOOD RIVER

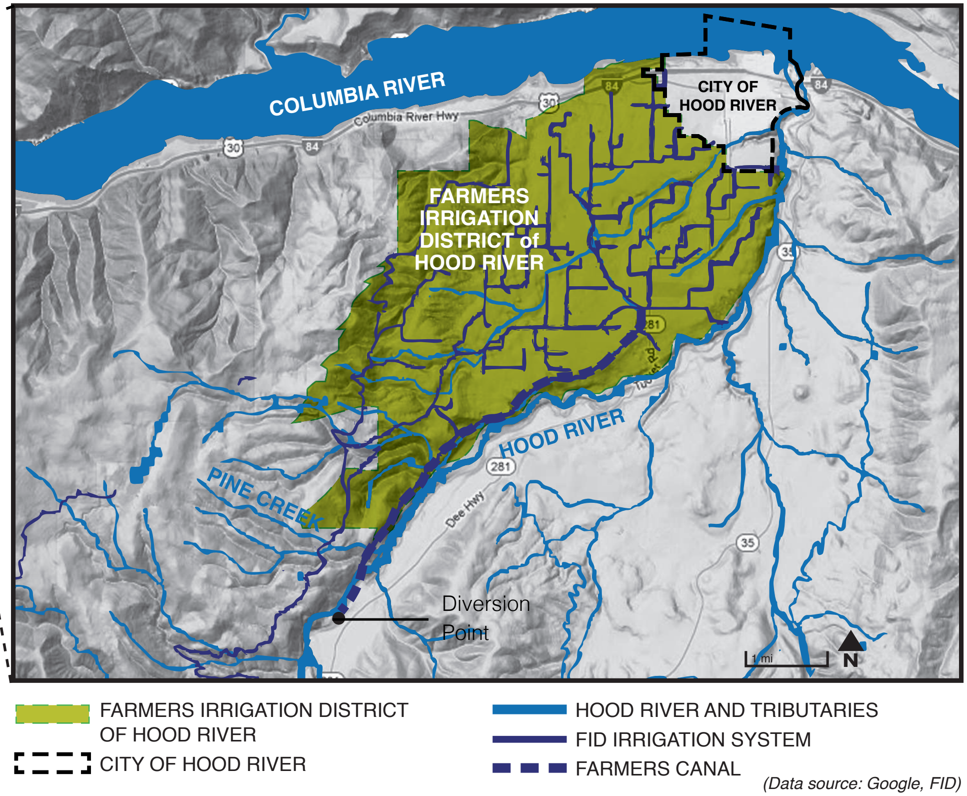


Figure 1. Farmers Irrigation District of Hood River Map

based on site variables and cost range.

Any site/strategy combinations not ruled out by the method are potential candidates for field testing. *(See figure 1 for a diagram of the method framework.)*

Research

To develop the extent, site variables, and cost range steps of the decision-making method, I conducted a review of academic studies, practitioner reports, and EPA best management practice recommendations.

I created a typology of landscape-based strategies with suspended sediment filtration function. In the interest of time, I selected three well-studied and heavily field-tested landscape-based strategies from the typology to use as examples: vegetated filters, compost filter socks, and constructed wetlands. I conducted a strengths, weaknesses, opportunities, and constraints (SWOT) analysis for each of the three example strategies, and used this information to complete the decision-making method framework.

I distilled each step of the decision-making method into a worksheet for ease of use.

Results

I applied the decision-making method to the Farmers Irrigation District of Hood River as a study site.

Through application of the landscape-scale analysis phase, I identified eight sources of sediment and nine potential build sites in the district. I ruled out constructed wetlands based on extent restraints for two of the potential sites.

Through application of the site-scale analysis phase, I ruled out vegetated filters based on site variables for eight out of the nine potential sites. I ruled out constructed wetlands based on site constraints for all seven stormwater input sites. I found that compost filter socks are possible but not ideal for all potential sites, and a vegetated filter is possible but not ideal for the Portland Road stormwater input site. I estimated cost ranges for the possible but not ideal strategies and found that implementation could be cost-effective for a 10 year period for all sites.

Next Steps

Future research steps should include:

1. Expanding the framework to include all of the potential landscape-based strategies.

2. Field testing the landscape-based strategies that are found to be potentially feasible by the method on the identified sites.

METHOD FRAMEWORK

PHASE I: LANDSCAPE-SCALE ANALYSIS

STEP 1: SCOPE

A. Identify sediment sources.

B. Identify potential sites.

STEP 2: EXTENT

C. Estimate extents of landscape-based strategies.

D. Rule out sites and strategies based on extents.

PHASE II: SITE-SCALE ANALYSIS

STEP 3: SITE VARIABLES

E. Rule out strategies based on key site variables. ??

STEP 4: COST

F. Rule out strategies based on cost range estimates. $$$

RESULTS

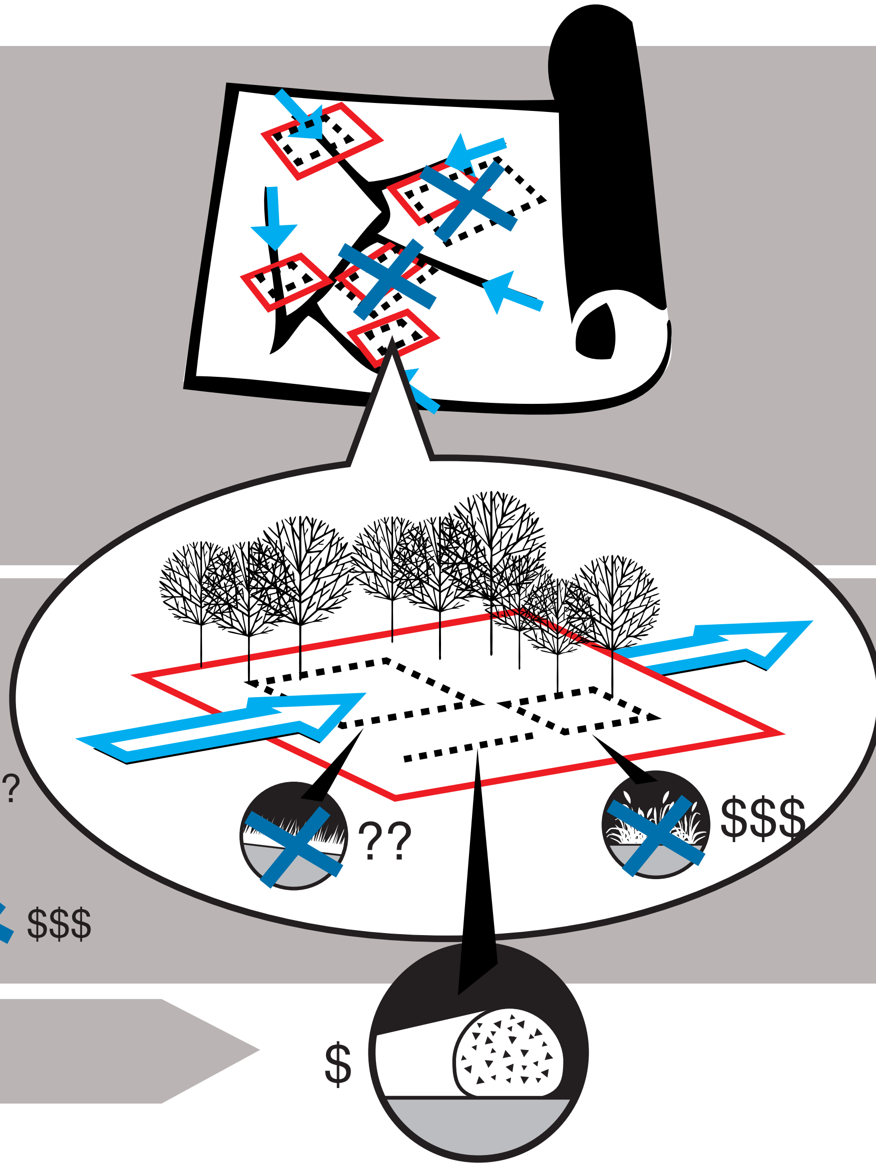


Figure 2. Method framework diagram

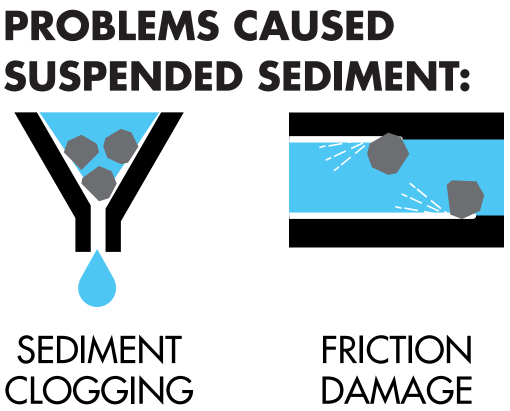


Figure 3. Clogging and Friction Damage

Problem Definition

This project takes the first step toward solving the problem of suspended sediment in irrigation water. Namely, to develop a method by which irrigation districts can decide whether landscape-based strategies are solutions worth pursuing. This section discusses both the greater suspended sediment problem, and the decision-making sub-problem.

The Problem of Suspended Sediment

The Environmental Protection Agency (EPA) uses the term 'suspended and bedded solids' (SABS) to describe "particulate organic and inorganic matter that are suspend in or carried by the water, and/or accumulate in a loose, unconsolidated form on the bottom of natural water bodies" (Swietlik 8). Other terms commonly used to describe these fine-grained water-borne particles include: clean sediment, suspended sediment, total suspended solids, bedload, turbidity, or in common terms, dirt, soils or eroded materials. For the purpose of this report, I will be using the term "suspended sediment."

This project aims to explore the potential for landscape-based strategies to solve the problems suspended sediment can cause in the context of agricultural irrigation systems. These problems can be broadly grouped into two categories: clogging and friction damage.

Clogging becomes a problem when water containing suspended sediment is pumped through irrigation equipment that possesses very small tubes or emitter holes. Sediment particles build up in these narrow spaces and block water from passing though (Lamm 486).

Drip irrigation, also known as micro-irrigation, trickle irrigation, or localized irrigation, is one type of irrigation system that is susceptible to clogging. A drip irrigation system conserves water by releasing it slowly, in drops or very small sprays, directly onto areas that require irrigation. This is accomplished through a network of valves, pumps, tubes, and water emitters, either above or below the soil surface. Drip irrigation systems can use up to 40% less water than traditional irrigation systems, and have been shown to have as high as a 90% application efficiency[1] (Camp 368).

Farmers install filtration systems to clean suspended sediment out of water before it enters their drip irrigation systems, but the cost to clean and maintain these filters is directly related to the volume of sediment being filtered out. A 2012 USDA report lists "Filtration/Water Treatment" and "Clogging" as the top two maintenance challenges to subsurface drip irrigation adoption (Lamm 486), and states that "A consistent, proactive management strategy of preventing problems, such as emitter plugging, is required instead of one where components are repaired or replaced after they fail" (Camp 368).

Friction damage becomes a problem when water containing suspended sediment is pumped at high pressure or speed through sensitive equipment.

1 Application efficiency is the volume of water needed by crops to avoid undesirable water stress, divided by the volume of water delivered to the field.

Friction wears away materials with which the sediment comes in contact.

Low-flow sprinkler systems and small-scale hydroelectric plants are examples of equipment susceptible to friction damage. Low-flow sprinklers depend on narrow emitter openings to control the rate of water they release. These narrow openings become wider through friction damage, thus increasing their flow and decreasing their efficiency. Small hydro-electric plants harness the energy supplied by flowing canal water to create electricity that can be used by the district or sold back to the grid. Sediment in canal water can erode machine hardware though friction damage. Repair and replacement of this hardware is expensive, and wastes energy and materials.

The Problem of Decision-Making

The task of deciding whether a landscape-based strategy is a feasible way to filter sediment on a site-by-site basis might be daunting and inefficient without a process framework. FID staff believes that a transferable method for making this kind of decision has the potential to save FID and other irrigation districts time, money, and administrative resources.

My sources of inspiration for decision-making theory and framework development are discussed below.

The Fermi Problem

Enrico Fermi was an Italian physicist who is best known for his work on the Manhattan Project in World War II (Von 10).

Fermi was also known for demonstrating how surprisingly accurate mathematical estimations could be based on available information and simple assumptions. Mathematical problems of this nature came to be known as "Fermi problems" (Von). Ross and Ross write that "[t] he essence of a Fermi problem is that a well-informed person can solve it (approximately) by a series of estimates."

The best-known example of a Fermi problem is one that is attributed to Fermi himself: "How many piano tuners are there in Chicago?" The answer to this problem is estimated through simple math and approximations of numerical data such as the total population of Chicago, the average number of persons per household, the percentage of households that posses a piano, the average number of times per year a piano is tuned, etc. The subsequent answer is not, naturally, expected to be accurate to the digit. However, if the approximations at each step are reasonably accurate, the answer will be a close enough estimation that it can safely be used to make preliminary decisions.

Dirks and Edge define the four factors "typically required" to solve a Fermi problem:

1. Sufficient understanding of the problem to decide what data might be useful in solving it.
2. Insight to conceive of useful simplifying assumptions.
3. An ability to estimate relevant physical quantities.
4. Some specific scientific knowledge.

With the understanding and insight I gained from my SWOT analyses, and FID's help with relevant physical quantities and specific knowledge, this project is largely an attempt to make a Fermi problem out of the question: "Are vegetated filters, compost filters, or constructed wetlands feasible landscape-based strategies for FID to field test?"

Mathematical Modeling

To translate the complexity of FID's situation into a solvable problem, it is necessary to create a conceptual, quantifiable model. I looked to mathematical modeling theory for guidance.

Rita Borromeo Ferri describes the mathematical modeling process in a cycle of six phases, catalyzed by six transitions:

Phase 1:	Real Situation
Transition 1:	*Understanding the Task*
Phase 2:	Mental Representation of the Situation
Transition 2:	*Simplifying/Structuring the Task*
Phase 3:	Real Model
Transition 3:	*Mathematizing*
Phase 4:	Mathematical Model
Transition 4:	*Working Mathematically*
Phase 5:	Mathematical Result
Transition 5:	*Interpreting*
Phase 6:	Real Results
Transition 6:	*Validating*

(which leads back to phase 1)

I adapted these phases and transitions with language appropriate to FID's context:

Phase 1:	FID's Problem
Transition 1:	*Building Understanding*
Phase 2:	Problem Comprehension
Transition 2:	*Framework Development*
Phase 3:	Real Framework
Transition 3:	*Abstraction & Simplification*
Phase 4:	Method Framework
Transition 4:	*Method Application*
Phase 5:	Method Results
Transition 5:	*Interpreting Results*
Phase 6:	Real Decisions
Transition 6:	*Validating*

My method development process and the structure of this document reflect this adapted version of Borromeo Ferri's modeling cycle.

Method Framework Precedent

Design of Stormwater Filtering Systems, a report prepared by Richard A. Claytor and Thomas R. Schueler for The Center for Watershed Protection, guides

MATHEMATICAL MODELING

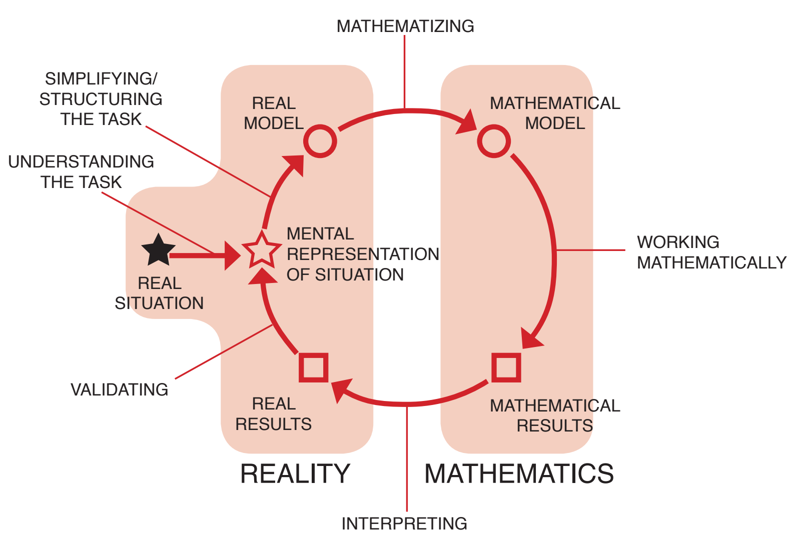


Figure 4a. The modeling cycle (Borromeo Ferri).

METHOD DEVELOPMENT

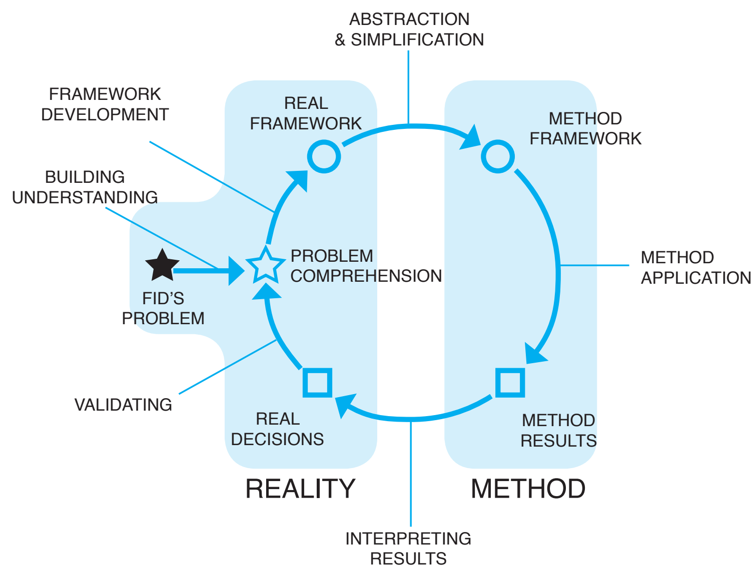


Figure 4b. The method development cycle.

practitioners in selecting and designing landscape-based stormwater solutions. This report served as a useful decision-making method framework precedent. Key sections helped me to structure FID's decision-making method logically and clearly, and aided me in identifying gaps in the method process. Listed below are sections I found particularly helpful:

1.2: Common Design Components
This section deconstructs the forms and functions of stormwater filter components. It informed my typology of built forms that reduce sediment in water.

1.3: Types of Stormwater Filtering Systems
This section describes various landscape-based strategies for filtering stormwater. It informed my typology of landscape-based strategies.

2.6: Stormwater Filtering Systems —Sizing Considerations
This section discusses how to estimate the required extent of stormwater filtering systems. It informed the extent step of my decision-making method.

3.1: Selecting the Best Stormwater Filter Design
This section discusses how to choose a stormwater filter type based on site variables. It informed the site variables step of my decision-making method.

Relevance

Solving irrigation districts' suspended sediment problems has the potential to do more than save farmers money and frustration. Suspended sediment damage may be an obstacle that is discouraging wider adoption of irrigation technologies that have ecological and human health benefits.

Water conservation:
If irrigation districts can filter the bulk of suspended sediment out of irrigation water before it reaches farms, equipment maintenance costs and overall frustration for farmers using drip irrigation, low-flow sprinklers, and similar technology will decrease, thus encouraging wider adoption of these water-conserving practices (Camp).

Water quality and topsoil conservation:
Over-irrigation practices wash topsoil and agricultural chemical inputs into streams and lakes (Shock, 2001). If water-conserving irrigation practices are more widely adopted by farmers, less over-watering will occur, which will help to preserve water quality and topsoil (Shock).

Energy conservation and production:
Energy and raw materials are expended to make irrigation and hydroelectric equipment. When equipment is damaged and requires replacement, those materials and energy go to waste. Less suspended sediment in irrigation water will result in less friction damage to equipment, thus conserving resources (ESHA).

Subsequent improved cost effectiveness of small hydro-electric plants could encourage wider adoption of this technology by irrigation districts, enabling the production of more district-scale electricity (ESHA).

Habitat preservation and restoration:
Unlike conventional hydroelectric plants that dam rivers and streams, irrigation canal powered hydro-electric plants don't require significant disturbance of natural water bodies. With wider adoption of small hydro, aging conventional dam infrastructure may be decommissioned and dismantled instead of repaired or replaced. Formerly dammed rivers have potential for restored function, with increased dynamism and seasonal flow cycles to enhance wildlife habitat.

Knowledge Gaps

Through review of journal articles, practitioner reports, and EPA best management practice (BMP) recommendations, I identified two key knowledge gaps.

Landscape-Based Strategies Applied to Irrigation Canal Water

Available literature includes studies and precedents for landscape-based strategies that filter suspended sediment out of stormwater, waste water, construction site runoff, and agricultural runoff, but not irrigation canal water. While the addressed sources can contribute to the sediment load in irrigation canals, their solutions address only pieces of the complex problem irrigation districts face.

Irrigation canals pose unique filtering variables including high flow rates and a constant press of water. Further complicating matters, stormwater filtration strategies often aim to optimize ground water recharge, while irrigation districts must retain as much of their allocated diversion water as possible.

Removing Suspended Sediment at High Flow Rates

Also lacking in available literature is any discussion of suspended sediment filtration at a macro scale, i.e. large water bodies such as rivers, lakes, and oceans. Extensive study has been done on sediment distribution in rivers, but most of this discussion applies to large particle sizes, i.e. gravel and boulders. This knowledge gap precludes the possibility of scaling down a tested macro solution, instead of scaling up a micro solution.

INTRO TO BUILDING UNDERSTANDING

The problems suspended sediment causes for irrigation districts (clogging and friction damage), can be mitigated by reducing the amount of suspended sediment in irrigation water. There are two principle processes that reduce sediment: sedimentation (or settling) and filtration. I found six types of built forms enable these processes: filters, forebays, barriers, resisters, infiltrators, and plains. I then found nine types of landscape-based strategies that employ sediment reducing built forms: vegetated filters, compost filters, constructed wetlands, swales, bioretention areas, detention ponds, gravel filters, sand filters, and silt fences.

I chose three well-researched and field-tested sediment reducing landscape-based strategies to use as examples with which to build a decision-making method framework: vegetated filters, compost filters, and constructed wetlands. I performed a strengths, weaknesses, opportunities, and threats analysis of each example strategy to inform the method framework.

BUILDING UNDERSTANDING

Decreasing Suspended Sediment

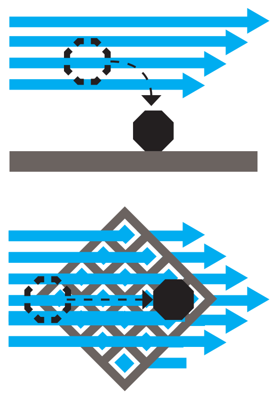
There are two principal processes through which the suspended sediment load in water is decreased—sedimentation and filtration (Claytor 4.1) *(see figure 5)*.

Sedimentation, otherwise known as settling of clarification, is the removal of solid particles due to the pull of gravity. Sedimentation is achieved when the velocity of water is lowered below the speed that will support transport of the particles, which allows gravity to remove them from the flow (Claytor).

Filtration is the trapping of solid particles in a substance, or filter media. Media can include woven materials like filter cloth or mesh, inorganic materials like gravel or sand, and organic materials like wood fiber or vegetation. Filtration is achieved when water flows through a filter media, leaving particles behind (Claytor).

Particles are filtered due to two processes: straining and adsorption. Straining occurs when gaps in the filter media are smaller than the particles, causing particles to remain trapped while water passes through (Claytor). Adsorption occurs when

PROCESSES THAT REDUCE SUSPENDED SEDIMENT



Sedimentation (settling)
Water is slowed, allowing gravity to remove sediment particles from the flow.

Filtration
Water flows through a filter media, leaving sediment particles behind.

Figure 5. Processes that reduce suspended sediment

particles stick to the surface of filter media materials due to complex physical forces (friction, etc) that attract and hold them. As most suspended sediment particles are smaller than the gaps in filter media, adsorption is the primary process by which suspended sediment is filtered (Claytor).

Typology of Built Forms That Remove Sediment

(See table 1 for summary)

Landscape-based strategies employ one or a series of built forms to achieve sedimentation and/or filtration of suspended sediment. I analyzed these forms and broke them down into six distinct types *(see figure 5)*.

Filter: A filter directs water through a filter media, in which solids become trapped. A sieve is an example of a filter. As soil-laden water is sifted through a sieve, soil particles that are smaller than the openings in the sieve pass through, while particles that are larger than the openings in the sieve remain. Landscape-based strategies use materials such as compost, sand, roots, and organic matter as filters. As water passes though the landscape filter, particles are strained or adsorbed.

Forebay: A forebay collects and stores

pooled water. A sink is an example of a forebay. When its drain is plugged, a sink collects water as it emits from a faucet. Landscape-based strategies use basins and ponds as forebays. As water flows into a pond, it collects into a pool. Sediment drops to the bottom of the pond due to sedimentation.

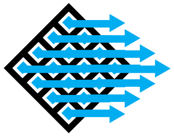
Barrier: A barrier halts or significantly slows the velocity of water by blocking its force with a solid form. A dam is an example of a barrier. As water flows against a dam, its forward velocity is stopped or re-directed. Landscape-based strategies employ berms, dams, and weirs made out of a variety of materials, such as rock, gravel, sand, concrete, or metal. When water slows or stops, sediment drops out due to sedimentation.

Resister: A resister slows the velocity of water by blocking its force with many small forms or an increase in surface area. The ribbed edge of a gold pan is an example of a resistor. As water passes over the edge of the pan, the raised ribs slow the water at the bottom of the flow, which causes the heaviest particles to drop out and remain in the pan. Landscape-based strategies use materials such as rocks, gravel, and vegetation to slow water and cause sedimentation.

Infiltrator: An infiltrator allows water to soak into the ground, thus decreasing the volume and velocity of water flows. A gravel driveway is an example of an infiltrator. When rain falls on a gravel driveway, as opposed to a concrete driveway, the gaps between the pieces of gravel allow water to trickle though the driveway surface to the ground beneath. This means less water runs off the driveway. Landscape-based strategies use substrate materials like sand, gravel, and roots to help water infiltrate into the ground.

Plain: A plain slows the velocity of water by allowing it to spread into a wider, flatter area. A hose flowing onto a driveway is an example of a plain. As the hose releases its concentrated stream of water onto a large, flat surface, the water spreads into a shallow sheet flow and slows down. Landscape-based strategies use flat, grass-covered strips, and broad, shallow pools to spread and slow water and cause sedimentation.

TYPOLOGY OF BUILT FORMS THAT REMOVE SUSPENDED SEDIMENT

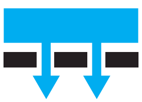


Filter—Allows water to flow through a filter media, to trap solids. A sieve is an example of a filter.

Forebay—Collects and stores pooled water. A pond is an example of a forebay.

Barrier—Halts or significantly slows the velocity of water by blocking its force with a large form. A dam is an example of a barrier.

Resister—Slows the velocity of water by blocking its force with an increase in surface area. The ribbed edge of a gold pan is an example of a resister.



Infiltrator—Allows water to soak into the ground. A gravel driveway is an example of an infiltrator.

Plain—Slows the velocity of water by allowing it to spread into a wider, flatter area. A hose flowing onto a driveway is an example of a plain.

Table 1. Typology of Built Forms That Remove Suspended Sediment

Typology of Landscape-Based Strategies That Remove Sediment

(See table 2 for summary)

I reviewed academic studies, practitioner reports, and EPA best management practice recommendations to identify landscape-based strategies that reduce suspended sediment. This section is a collection of brief descriptions of each of the landscape-based strategies I identified.

Vegetated filters are flat, sloped plains of vegetation used to filter a sheet flow of water. They were originally developed to treat agricultural runoff (EPA, 2000), but they have since been adapted for urban stormwater (Claytor 1.17). They help manage flooding by slowing and infiltrating stormwater before it runs into rivers and streams (EPA).

Vegetated filters remove suspended sediment through sedimentation and filtration processes (Cahill 1). Sedimentation occurs as the velocity of water slows due to the resistance provided by dense ground cover vegetation (Cahill). Filtration occurs as sediment is trapped by soil, sand, and plants (Cahill).

Vegetated filters are also known as vegetated filter strips, grassed filter strips, filter strips, and grassed filters.

Compost filters are made of a variety of organic composted materials including feedstocks, municipal yard trimmings, food residuals, separated municipal solid waste, biosolids, and manure (EPA). They are installed in the form of berms, mats, and socks (EPA). Compost socks are biodegradable mesh tubes filled with compost (Archuelta 1). Compost filters are installed perpendicular to a sheet or concentrated flow of water to prevent erosion and remove pollutants (Archuelta). They are used to filter stormwater, construction site runoff, and agricultural runoff (EPA). Compost socks and berms help to manage flooding by slowing and temporarily storing stormwater (Archuelta).

Compost filters remove suspended sediment through sedimentation and filtration processes (Archuelta). Compost berms and socks cause water to pool behind them, slowing its velocity nearly to a halt, initiating sedimentation (Archuelta). Sediment is strained and adsorbed as water flows through the composted material (Archuelta).

Constructed wetlands are shallow pools, sometimes built in a series, planted with wetland vegetation (EPA). They are designed to settle, filter, and absorb particles and pollutants from water that enters through one end of the system and exits through the other end. Constructed wetlands are on the complex end of the landscape-based strategy spectrum, as they often include forebay and wet pond pre-treatment pools and they can support a diverse plant community (Capiella). They are used to treat stormwater, agricultural runoff, and wastewater, and they help to control flooding by providing flood storage in their pre-treatment and wetland pools (EPA).

Constructed wetlands remove suspended sediment through sedimentation and filtration processes (Capiella). Sediment settles to the bottom of their pre-treatment pools and is strained and adsorbed as it passes through wetland vegetation (Capiella).

Constructed wetlands are also known as stormwater wetlands or reed beds.

Swales are open, vegetated channels designed to capture, filter, and infiltrate water (EPA). They are used to treat stormwater and agricultural runoff, and they help to manage flooding by capturing and infiltrating stormwater (EPA).

Swales remove suspended sediment through sedimentation and filtration practices (EPA). Sediment settles to the bottom of swales when water is captured or slowed, and is strained and adsorbed as it passes through dense ground-cover vegetation (EPA).

Swales are also known as grassed swales, grassed channels, dry swales, wet swales, biofilters, or bioswales.

Bioretention areas are shallow, landscaped depressions designed to treat and infiltrate urban stormwater on-site (EPA). They often receive runoff from parking lots and roof gutters (EPA). They help to manage flooding by storing and infiltrating stormwater instead of releasing it into sewers or streams (EPA).

Bioretention areas remove sediment through sedimentation and filtration processes (EPA). Sediment settles to the bottom of the bioretention area as the water's velocity is slowed or halted, and is strained and adsorbed by gravel, sand, and vegetation (EPA).

Bioretention areas are also known as rain gardens.

Detention ponds are vegetated or unvegetated basins with inlets and drains that are designed to store water for a specific period of time to allow particles to settle (EPA). They help to manage flooding by providing temporary storage for stormwater (EPA).

Detention ponds remove suspended sediment through the sedimentation process (EPA). Sediment settles out of water when its velocity is slowed or halted in the basin (EPA). If the basin is vegetated, some filtration may also occur (EPA).

Detention ponds are also known as dry ponds, extended detention basins, detention ponds, and extended detention ponds.

Gravel filters come in a variety of forms, such as berms, shallow dry beds with or without outlet drains, and deeper beds with permanent pools and wetland vegetation (Matt 2513, Claytor). The earliest gravel filters, of the berm and dry bed varieties, were designed to store and infiltrate stormwater, but the added benefit of sediment and pollutant removal has led to their wider use and adaptation for construction-site erosion control and stormwater treatment (Matt).

Gravel filters remove suspended sediment through the sedimentation and filtration processes (Matt). Water is slowed by the gravel, which acts as either a barrier or a resister, depending on the design of the filter, causing sedimentation (Matt). Sediment is strained and adsorbed as water flows through the gravel (Matt).

Gravel filters are also known as submerged gravel filters, gravel berms, gravel infiltration systems, and gravel wetlands.

Sand filters come in a variety of designs, including underground, surface, perimeter, and organic (Claytor). They are used to treat stormwater and wastewater for particles, pollutants, and organic solids.

Sand filters remove suspended sediment through the sedimentation and filtration processes. Water is slowed as it pools in and above the sand, causing sedimentation. Sediment is strained and adsorbed as water flows through the sand.

Sand filters are also known as underground sand filters, surface sand filters, perimeter sand filters, and organic sand filters.

Silt fences are temporary barriers made of filter cloth and held up by posts, built around the perimeter of a construction site or on a slope to intercept stormwater and reduce erosion. They are a minimum measure, and have been shown to be less effective than compost filters (Faucette).

Silt fences remove suspended sediment through the sedimentation and filtration processes. The velocity of water is slowed or stopped as it pools behind the barrier, causing sedimentation (EPA). Sediment is strained and adsorbed as water passes through the filter cloth.

Selecting Three Example Strategies

In the interest of time, I selected three landscape-based strategies to use as examples with which to build a decision-making method framework. I based my selection on how many relevant articles a search for each landscape-based strategy produced in Google Scholar. Google Scholar is an on-line search engine that searches for literature (using key words) from a wide variety of sources including books, journal articles, government reports, and abstracts. I chose to select strategies through this process:

1. to assure that there would be ample literature from which to draw information about each example strategy, and
2. with the assumption that the most written-about strategies will have been implemented and tested in the field, thus providing for data on their necessary extents, site variables, and costs.

My search criteria had two steps.

1. Search for : “(name of landscape-based strategy)” filter suspended sediment
2. Confirm that the first 10 resulting articles related to the target filter type and to suspended sediment filtration. If they did not, I modified the quoted text and searched again. (The text in the first column of table 1 reflects the final, successful search term.)

Vegetated filters returned the highest number of articles by a considerable amount, with 9010. Compost filters came in second, with 4120. Constructed wetlands came in third, with 3410. *(See table 2)*

I narrowed the compost filter category to compost filter socks, specifically, because the EPA stormwater BMP guidelines indicated that they are the most effective and versatile of the compost filters. For the duration of the project, I use these three landscape-based strategies as examples on which to base a method framework, with the expectation that the method can be broadened to include all nine of the landscape-based strategies as a future research step.

TYPOLOGY OF LANDSCAPE-BASED STRATEGIES

FILTER TYPE	APPLICATIONS					FORM TYPES						ACTIONS		# OF HITS
	STORMWATER	AG RUNOFF	CONSTRUCTION RUNOFF	WASTEWATER	FLOOD MANAGEMENT	FILTER	FOREBAY	BARRIER	RESISTER	INFILTRATOR	PLAIN	FILTRATION	SEDIMENTATION	
vegetated filter	●	●	○	○	●	●	○	○	●	●	●	●	●	9010
compost filter	●	●	●	○	●	●	○	●	○	○	○	●	●	4120
constructed wetland	●	●	○	●	●	●	●	○	●	○	●	●	●	3410
swale	●	●	○	○	●	●	●	○	●	●	○	●	●	1770
bioretention area	●	○	○	○	●	●	●	○	●	●	○	●	●	994
detention pond	●	●	○	●	●	○	●	○	○	○	○	◒	●	917
gravel filter	●	○	●	○	●	●	●	○	○	◒	○	●	●	509
sand filter	●	○	○	●	●	●	●	○	○	●	○	●	●	346
silt fence	●	○	●	○	○	●	○	●	○	○	○	●	●	317

● APPLIES ◒ SOMEWHAT APPLIES ○ DOES NOT APPLY

Table 2. Typology of Landscape-based Strategies

Strengths, Weaknesses, Opportunities, and Threats (SWOT) Analyses of Three Selected Landscape-Based Strategies

This section describes the strengths, weaknesses, opportunities (for implementation), and threats (that would obstruct implementation) of each of the three selected landscape-based strategies, compiled from EPA, state and local BMP recommendations, practitioner reports, and academic studies.

Vegetated Filter SWOT Analysis

(see table 3 for summary)

Strengths

- Effective sediment removal—47% of clay, 92% of silt, >92% of sand (Abu-Zreig, 2001).
- Medium construction expense—$13,000–$30,000 per acre (EPA).
- Medium habitat potential—diverse native vegetation can be used, as long as dense ground cover is include (Claytor).
- High Aesthetic potential—can be designed to look natural or landscaped (Claytor).
- Installation, removal, or alteration is medium to low difficulty—depending on size and complexity of design (PA DEP).
- Pollutant and nutrient removal. (EPA)

Weaknesses

- Plants cannot tolerate high or constant flows—requires upland species (Claytor).
- Plants need partial to full sun—full canopy will shade out ground cover species (Claytor).
- Plants require good drainage—soil class must be moderately well to well drained (EPA).
- Loss of water due to infiltration, transpiration, and evaporation (Claytor).
- Works best when combined with other measures, such as bioretention areas (PA DEP).
- Area of land needed is approximately 100% of impervious surface drained, or 1:6 ratio with pervious surface drained (Claytor).
- Medium maintenance cost —$100-$1400 per acre, per year. (PA DEP)
- Requires a sheet flow of water, which can be difficult to maintain in filters wider than 150 ft (EPA).

Opportunities

- Stormwater and irrigation runoff entering open canals—vegetated filters might be installed as a landscape-based system along canal banks.
- Stormwater and irrigation runoff entering canal inlets, as long as sheet flow can be maintained—vegetated filters might be installed to intercept water before it is channeled into piped canals.
- Natural areas, if not already functioning to remove sediment, can be enhanced with restorative ground cover vegetation, and/or a pea gravel diaphragm (aka level spreader) can be constructed to establish sheet-flow. (PA DEP)

Threats

- Constant or deep water flow—1 inch depth or less, ideally (Clar 85).
- High water table—must be at least 2 ft below lowest point of the filter site (PA DEP).

- Steep slopes —2-6% ideally, 6%-15% maximum (Clar).
- Zero slope—needs at least 2% to keep water moving (Clar).
- Incised flows—sheet flow often converts to concentrated flows after 75-100 ft (Clar). Pea gravel diaphragms (aka level spreaders) can be used to re-establish sheet flows (Claytor).
- Full canopy cover—site trees and shrubs might need to be thinned to establish ground cover.
- Habitat areas—if natural areas are not already functioning to remove sediment, some disturbance of vegetation, soil and hydrology might be necessary to promote function.

Compost Filter Socks

(see table 4 for summary)

Strengths

- Effective sediment removal—65% of clay, 66% of silt, 90% of sand (Faucette, 2006).
- Low construction expense—$3-$10 per linear foot (EPA cost worksheet).
- Low maintenance expense—approximately $0.20-$0.50 per linear foot per year (EPA cost worksheet).
- Can be easily removed—if compost can be left on-site, only filter mesh requires removal (EPA).
- Flexible sizing—comes in sock diameters of 8 in., 12 in., 24 in., and 32 in. Can be pre-filled or filled on-site to any specified length (Faucette).
- Pollutant and nutrient removal. (EPA)
- Potentially no need for trenching or soil disturbance if consistent contact with the soil is possible without action (EPA).

Weaknesses

- Little habitat potential—although compost filters can be seeded with vegetation if desired (EPA).
- Need for frequent replacement—at least twice per year, depending on sediment loads and flow rates (EPA).
- Low aesthetic potential—although landscape can be designed to screen from view (EPA).
- Requires sheet flows or very light concentrated flows—EPA recommends not using compost filter socks for perennial waterways.
- Would require large areas of surface water for high flows—at most, they can handle four cubic feet per minute for each linear foot of sock. Four cubic feet per minute is equal to approximately 1.6 acre inches per day.
- Loss of water due to evaporation, infiltration, and plant uptake, depending on site conditions (Faucette).

Opportunities

- Stormwater and irrigation runoff entering open canals—compost filter socks might be installed as a landscape-based system along canal banks.
- Stormwater and irrigation runoff

entering canal inlets—compost filter socks might be installed to intercept water before it is channeled into piped canals.

- Diversion points or main canals—compost filter socks could be used to filter diversion water, if a very large site could be permanently flooded to achieve sheet flow.

- Sub-canals—compost filter socks could be used to filter canal water if a reasonably large site could be permanently flooded to achieve sheet flow.

Threats

- Habitat areas—installation of compost filter socks may require some disturbance of vegetation, soil or site hydrology.

- Permanent need—compost filter socks are designed to be temporary solutions. Their capacity to effectively filter suspended sediment is diminished through use. They require at least semi-yearly replacement.

Constructed Wetland

(see table 5 for summary)

Strengths

- Effective sediment filter—47% of fine clay, 62% of clay, 76% of silt, and 99% of sand (Braskerud).

- High habitat potential—constructed wetlands do not have the same degree of biodiversity or habitat function as natural wetlands, but they can be designed with diverse native plants (EPA).

- High aesthetic potential—constructed wetlands can be designed to look natural or landscaped, and can increase the value of adjacent lands (Capiella).

Weaknesses

- Cannot be easily removed or altered—constructed wetlands require more complex grading, engineering, and hydrology infrastructure than the other two selected landscape-based strategies. They are built to be permanent strategies (EPA).

- High construction expense— $38,000-$198,000 per acre (Entrix).

- High maintenance expense— $1,300-$9,900 per acre per year (or about 3-5% of construction cost) (Sample).

- Requires a relatively flat site—2-5% slope is ideal (Capiella).

- Plants cannot tolerate intermittent flows—consistent pool depths are necessary to support diverse wetland plant communities (Capiella).

- Plants prefer full sun if the landscape is designed as an emergent wetland, and partial sun if it is designed as a wooded wetland (Capiella).

- Plants require heavy, poorly drained soils—wetland plants require inundated roots (Capiella).

- Loss of water due to transpiration and evaporation—large, shallow wetland pools are susceptible to heating in the sun, and wetland plants absorb moisture and release it into the atmosphere (EPA).

- Large size requirements for high flows—wetland and pre-treatment pools must be sized to store and slowly process water (Rousseau, 2004).

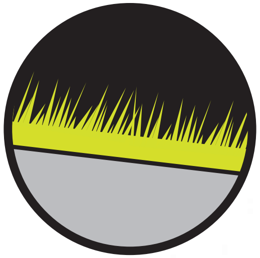
Opportunities

- Diversion or main canal—constructed wetlands might be used to filter diversion water, but it is likely that their necessary land area would be prohibitive with such a high flow rate of water.

- Sub-canals—same as main canals.
- Irrigation runoff with constant water drainage or consistent stormwater drainage—constructed wetlands need enough water to maintain wetland function at all times. This might be achieved with a constant source of water, or from stored water released over time.

Threats
- A water source that is not consistent enough to maintain wetland function.
- Steep slopes—anything above 5% is not ideal (Capiella).
- Well-drained soils.
- Full or medium current canopy cover—trees and upland plants would need to be removed or thinned.
- Habitat areas—installation of a constructed wetland would disturb vegetation, soil, and site hydrology.
- Temporary need—a constructed wetland would not be a practical temporary solution.
- Small site—constructed wetlands require large land areas.

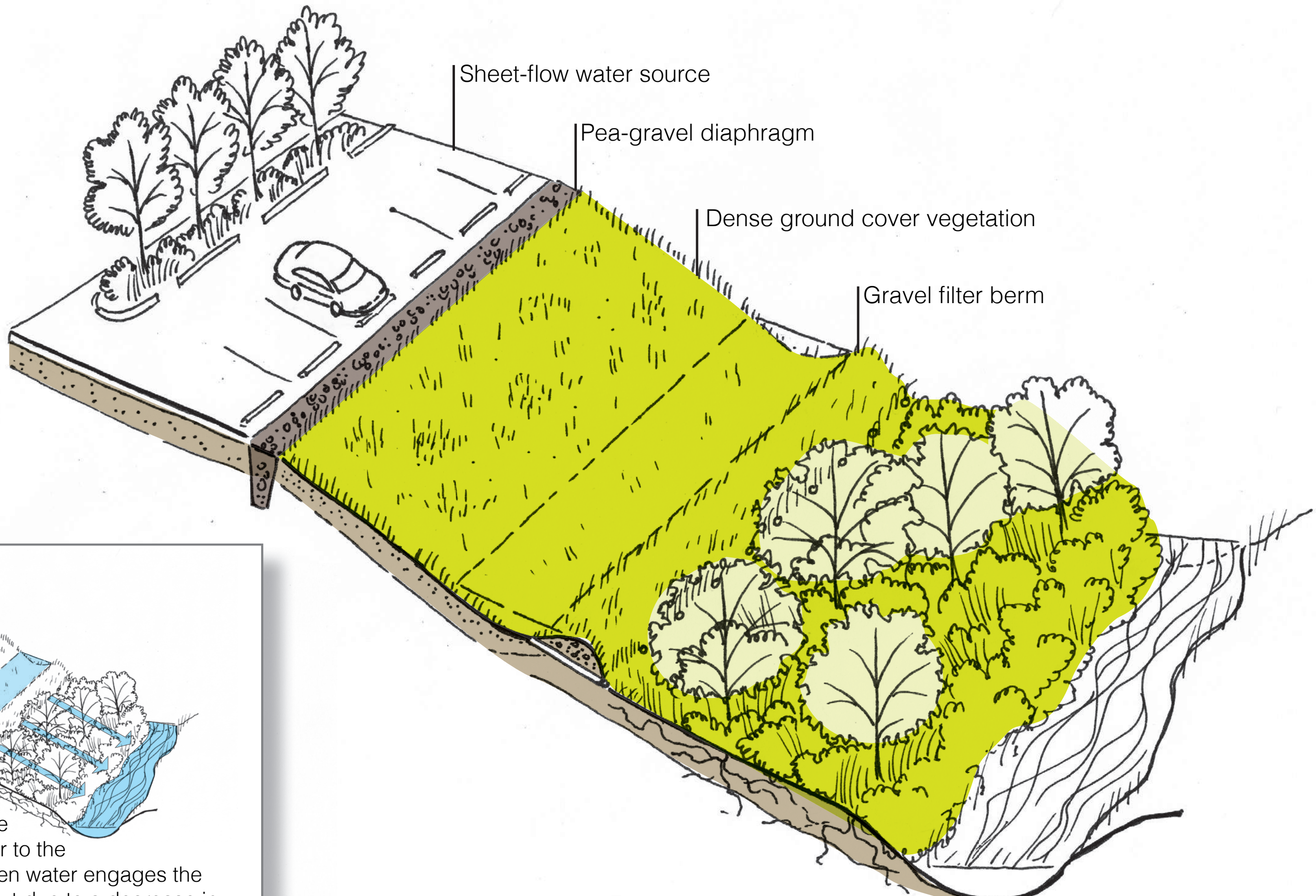
Results of SWOT Analyses
Through the SWOT analyses, I identified a list of variables that could help an irrigation district determine the feasibility of the three example strategies on an identified site. Those variables include extent, water source type (pulse v. press as well as sheet flow v. concentrated flow), target sediment particle size, slope, soil drainage, depth to water table, canopy cover, duration of project, and cost.

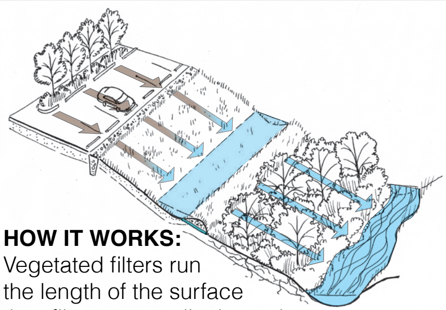


VEGETATED FILTER

What is it?

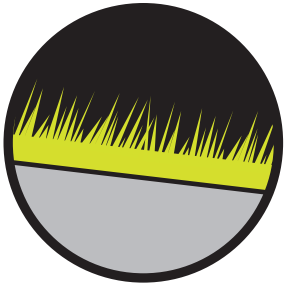
In a **meadow**, water is slowed, infiltrated, and filtered as it passes through dense vegetation. Practitioners mimic this natural process with **vegetated filters**, which are implemented as wide strips of turf grass, meadow plants, or forest with dense ground cover.





HOW IT WORKS:
Vegetated filters run the length of the surface they filter, perpendicular to the sheet-flow of water. When water engages the filter, sediment settles out due to a decrease in velocity, and is filtered out as the water passes through dense vegetation.

Figure 6. Vegetated Filter Diagram



VEGETATED FILTER SWOT SUMMARY

STRENGTHS

- Effective sediment removal—47% clay, 92% silt, >92% sand.
- Medium construction expense —$13,000–$30,000 per acre.
- Medium maintenance cost —$100-$1400 per acre, per year.
- Medium habitat potential.
- High Aesthetic potential.
- Removal is medium to low difficulty.

WEAKNESSES

- Plants cannot tolerate high or constant flows.
- Plants need partial to full sun and good drainage.
- Loss of water due to infiltration, transpiration, and evaporation.
- Works best when combined with other measures.
- Requires a sheet flow of water.

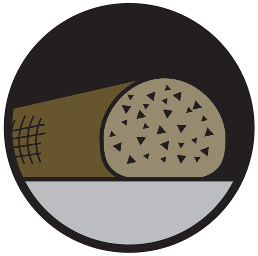
OPPORTUNITIES

- Stormwater and irrigation runoff entering open canals.
- Stormwater and irrigation runoff entering canal inlets.
- Natural areas can be enhanced.

THREATS

- Constant or deep water flow.
- High water table.
- Steep slopes.
- Zero slope.
- Incised flows.
- Full canopy cover.
- Habitat areas.

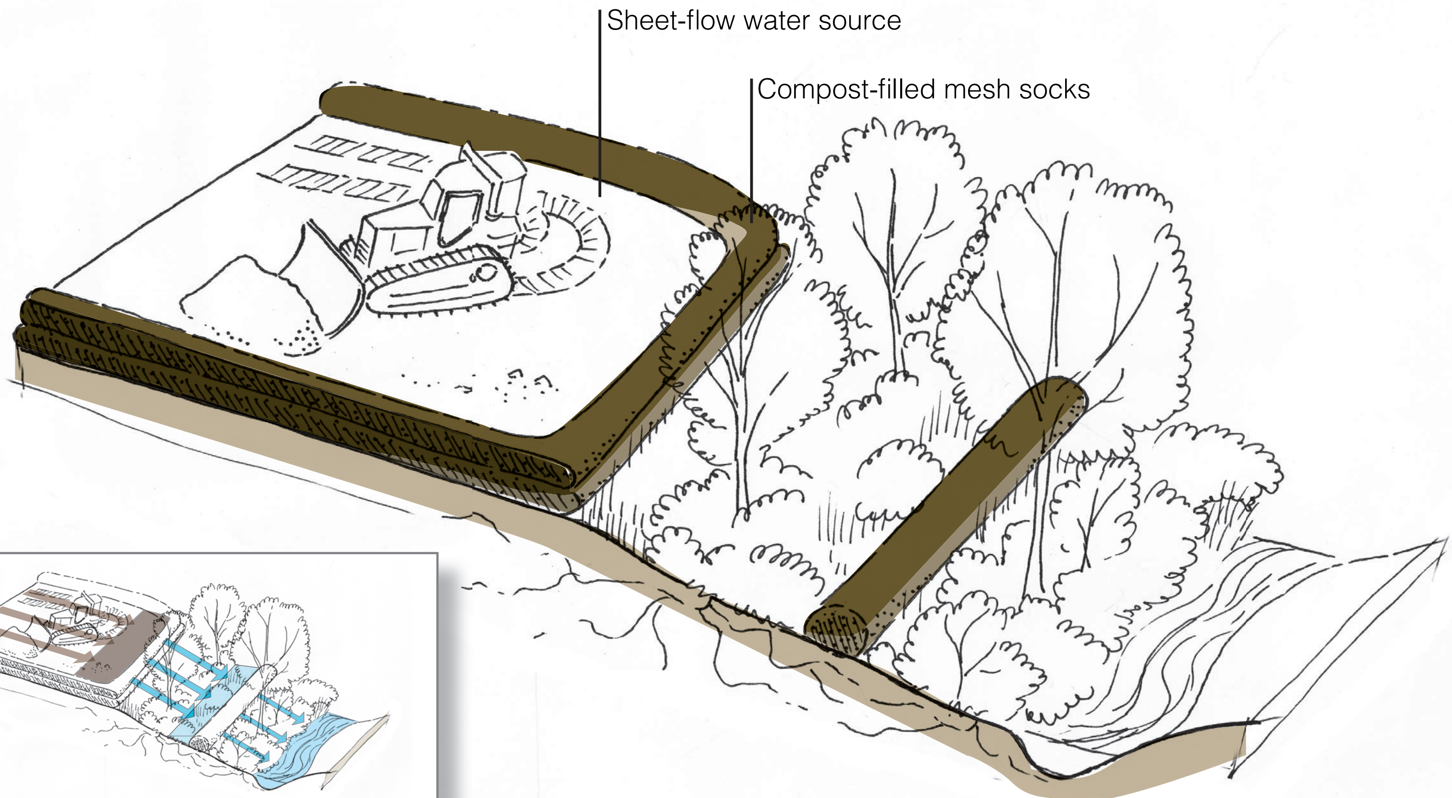
Table 3. Vegetated filter SWOT analysis



COMPOST FILTER SOCK

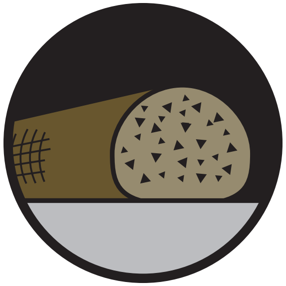
What is it?

On the forest floor, water is slowed and filtered by a thick layer of decaying organic matter. Practitioners mimic this natural process with **compost filters**, which are implemented as berms, mats, or socks. Socks are the most versatile, as they contain the loose compost filter medium in a large mesh tube, making them easy to install, maneuver, stack, and remove.



HOW IT WORKS: Compost filters are aligned perpendicular to the sheet-flow of water. When water engages the filter, sediment settles out due to a decrease in velocity, and is filtered out as the water passes through the compost.

Figure 7. Compost Filter Sock Diagram



COMPOST FILTER SOCK SWOT SUMMARY

STRENGTHS

- Effective sediment removal—65% clay, 66% silt, 90% sand.
- Low construction expense—$3-$10 per linear foot.
- Low maintenance cost—$0.20-$0.50 per linear foot per year.
- Can be easily removed.
- Flexible sizing.
- Low need for soil disturbance.

WEAKNESSES

- Low habitat potential.
- Need for frequent replacement.
- Low aesthetic potential.
- Requires sheet flows or very light concentrated flows.
- Would require large areas of surface water for high flows.
- Loss of water due to infiltration.

OPPORTUNITIES

- Stormwater and irrigation runoff entering open canals.
- Stormwater and irrigation runoff entering canal inlets.
- Diversion points or main canals.
- Sub-canals.

THREATS

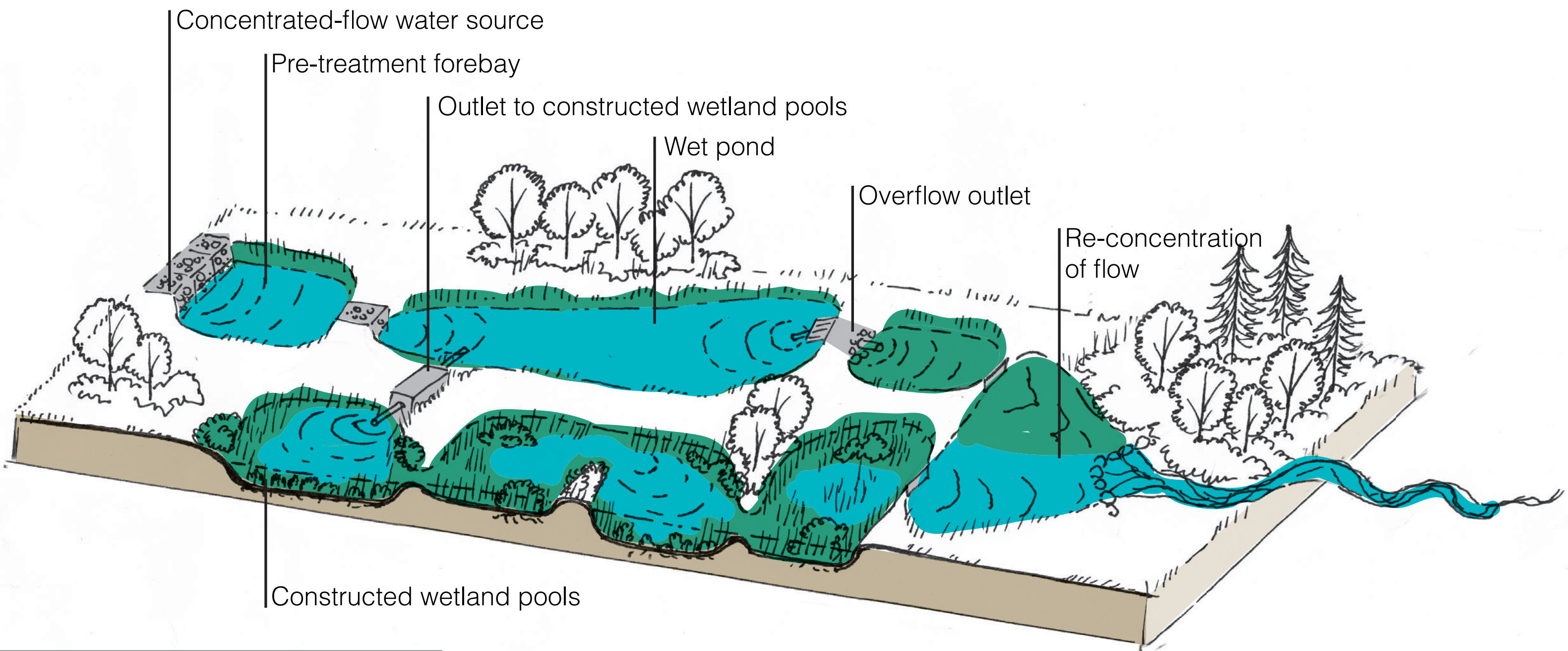
- Habitat areas—may require some disturbance of vegetation, soil or site hydrology.
- Permanent need—compost filter socks are designed to be temporary solutions.

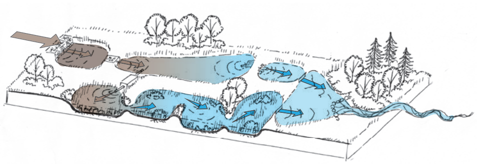
Table 4. Compost filter sock SWOT analysis

CONSTRUCTED WETLAND

What is it?

In a natural wetland, water is slowed and filtered at it spreads into shallow pools and passes through wetland vegetation. Practitioners mimic this natural process with **constructed wetlands**, which are implemented alone, in a series, or in conjunction with a settling pond.





HOW IT WORKS: Constructed wetlands are built to intercept a stream of water. When water engages the filter, sediment settles out due to a decrease in velocity, and is filtered out as the water passes through wetland vegetation.

Figure 8. Constructed wetland diagram

CONSTRUCTED WETLAND SWOT SUMMARY

STRENGTHS

- Effective sediment filter—62% clay, 76% silt, and 99% sand.
- High habitat potential..
- High aesthetic potential.

WEAKNESSES

- Cannot be easily removed.
- High construction expense.
- High maintenance expense.
- Requires a flat site—2-5% slope.
- Plants cannot tolerate varied flows and prefer full sun and poorly drained soils.
- Loss of water due to transpiration and evaporation.
- Large extent requirements.

OPPORTUNITIES

- Diversion or main canal.
- Sub-canals.
- Irrigation runoff with constant water drainage or consistent stormwater drainage.

THREATS

- An inconsistent water source.
- Steep slopes.
- Well-drained soils.
- Full canopy cover.
- Habitat areas—would disturb vegetation, soil, and site hydrology.
- Temporary need.
- Small site.

Table 5. Constructed wetland SWOT analysis

INTRO TO METHOD FRAMEWORK DEVELOPMENT

Variables that could help an irrigation district determine the feasibility of the three example strategies on an identified site include: extent, water source type (pulse v. press as well as sheet flow v. concentrated flow), target sediment particle size, slope, soil drainage, depth to water table, canopy cover, duration of project, and cost.

In this chapter, I explain how I used these variables to create a step-by-step method using that irrigation districts can use to identify sites where landscape-based strategies might be built to reduce suspended sediment, and then narrow down their options to only the most feasible site/strategy combinations. By ruling out infeasible sites and landscape-based strategies, irrigation districts can save time and resources that might otherwise be spent pursuing infeasible solutions.

METHOD FRAMEWORK DEVELOPMENT

Method Framework Summary

(See figure 2 for a process diagram)

The method framework described in this chapter will enable irrigation districts to determine quickly whether the three example landscape-based strategies are feasible for irrigation districts to field test as sediment filtration solutions.

Phase one of the method is a landscape-scale analysis. The first step in this phase determines the scope of the problem by identifying likely suspended sediment sources and loosely mapping potential sites where landscape-based strategies could be built. The second step in the landscape-analysis phase uses simple equations to generate extent ranges for the three example landscape-based strategies, based on the flow rate of water they would need to filter at each potential site. These estimates would allow an irrigation district to rule out sites that don't contain enough area to support any of the three example landscape-based strategies, and conversely to rule out landscape-based strategies whose extent would require too much area for all potential sites.

Phase two of the method is a site-scale analysis. It is applied to each of the remaining potential sites. Its first step uses a simple worksheet to rule out landscape-based strategies based on their site variable requirements. Its second and final step uses simple equations to generate an estimated cost range for each of the remaining landscape-based strategies, based on their previously estimated extent range at each potential site. Unlike the previous steps that are designed to determine whether example strategies can be applied, the cost step is designed to determine whether landscape-based strategies should be applied. Any example strategies whose entire cost range is unacceptable by the district are ruled out.

Example strategies that are not ruled out based on extent, site variables, or cost are determined to be feasible candidates for further design research and field-testing on the identified potential sites.

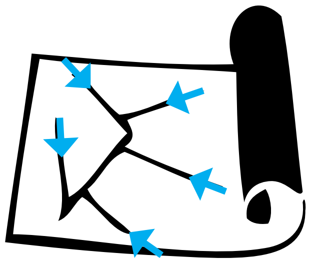
Phase I: Landscape-Scale Analysis

Landscape-scale analysis is the first phase of the method. This section describes the scope and extent steps in detail and explains how I developed them based on the research in the previous section.

Step 1. Scope

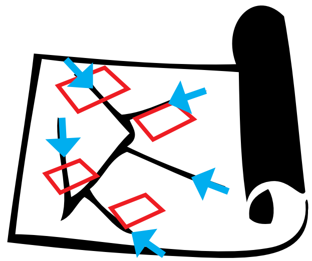
(see worksheet 1 for summary steps)

To determine the scope of a problem is to quantify the number and extent of its parts. This step asks the irrigation district to consider the number and extent of both its sources for suspended sediment and its potential sites for building landscape-based strategies to filter that sediment. This prevents districts from wasting time and resources by vetting individual sites in detail or looking for solutions to a single suspended sediment source without first having considered the problem holistically. To perform the scope defining portion of the method, the district will need a map of their canal system.



A. Suspended Sediment Sources:
Where is sediment entering the system?
To solve the problem of suspended sediment, a district must first determine the source or sources of its suspended sediment. Suspended sediment can enter a district's canal system at its diversion point. For example, a river may carry a load of sediment due to steep slopes and fine deposits upstream. Sediment can also enter irrigation canals during storm events. For example, stormwater may collect sediment as it flows through open construction sites or tilled agricultural fields. Over-irrigation by farms can also wash topsoil downhill and into canals. Water can enter irrigation canals in the form of sheet-flows over flat land or in the form of concentrated flows collected by incised channels.

Identify potential sources for suspended sediment and mark them on the district map.



B. Potential Sites:
Where might strategies be built?
Landscape-based strategies require a considerable amount of space to allow the sedimentation and filtration processes to happen. Districts need to identify areas of land that are well-situated to intercept suspended sediment sources before they enter the system, or areas of land where sediment-laden irrigation water that is already in the system might be slowed and filtered.

Some types of areas to consider include:

At the diversion. Is sediment entering from a diversion source? Maybe there is land at or near the diversion site where sediment could be filtered out before it enters the system.

On a main canal. Is there a site on or near a main canal where sediment could be filtered out before the canal splits off into sub-canals? This may be an opportunity to filter sediment efficiently with one large landscape-based strategy.

On sub-canals. Maybe it would make sense to have multiple smaller landscape interventions instead of one large one. This might allow a district to intercept all of the suspended sediment that collects from multiple sources along open canals.

On canal banks. If sediment-laden stormwater or agricultural runoff enters along the banks of open canals, maybe a landscape-based strategy system could line the banks to intercept the sheet-flow source.

At concentrated stormwater inputs. Some irrigation districts direct stormwater into their canal system via designated inputs. Is there an area of land just outside the input or inputs where water could be filtered before it enters the system?

At end-user draw points. A network of landscape-based strategies that filter sediment as water is being drawn out for end-user consumption might be the answer.

Identify potential build sites for landscape-based strategies and mark them on the district map.

Step 2. Extent

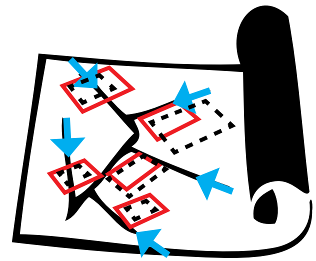
(see worksheet 2 for summary)

This step uses simple equations to estimate the extent range of each landscape-based solution at a given site. Subsequently, this step should be repeated for each potential site that was identified in the previous step. Broadly, extent could be a measure of area, volume, length, height, etc. In this example, extent is a measure of area in square feet for vegetated filters, a measure of length in linear feet for compost filter socks, and a measure of area in acres for constructed wetlands.

To complete this step, an irrigation district will need the estimated area, length along the longest level topography line, and estimated flow rates of water for each potential site. It is important to keep in mind the difference between a press source of water, which has a constant flow rate, and a pulse source of water, with will have periods of high flows followed by periods of low or no flows. With a press source, the constant or maximum flow rate should be used, as water needs to exit the landscape-based strategy at the same rate that it enters or it will continue to pool until it overflows the strategy. With a pulse source, the landscape-based strategy can be designed to either filter the pulse of water as it occurs, or to store a volume of water during the pulse event and release it slowly during periods of low or no flow. In the former case, the peak flow rate during a design storm should be used.[1] In the latter case, the flow rate should be determined based on the estimated volume of the design storm, and the amount of time it should take for drainage to occur. This estimate can be complex and varies by climate. (See appendix C for more information on how to estimate the volume of a design storm.)

Use the extent range equations below to estimate extent ranges for all landscape-based strategies at each potential site. (An Excel spreadsheet will speed calculations.)

1 A design storm is a hypothetical storm, based on precipitation patterns in a site's surrounding area. Design storms have set rainfall depths for 2 year, 5 year, 10 year, and 100 year storm events.



C. Estimate extents of landscape-based strategies.

Vegetated Filter Extent Range

This estimation equation is adapted from the EPA's Stormwater Best Management Practice Design Guide (Clar et al, 2004). Vegetated filters can effectively treat 3 cfm of water for every foot in length of vegetated filter. Vegetated filter widths between 20 ft (min) and 300 ft (max) can effectively maintain a sheet flow of water if they are designed and built appropriately. Pea gravel diaphragms can effectively re-establish sheet flow in between these intervals, if necessary.

Extent Range Equations:

$A(min) = 20*(q/3)$

$A(max) = 300*(q/3)$

Where A(min) is minimum required area of vegetated filter in square feet, A(max) is maximum required area of vegetated filter in square feet, and q is flow rate in cubic feet per minute.

Compost Sock Extent Range

This extent range equation is based on the flow-through rates of compost socks, as reported by the USDA (Faucette , 2010). The minimum length is based on the flow-through rate of a compost sock with a 32-inch diameter (4 cfm per linear foot). The maximum length is based on the flow-through rate of a compost sock with a 12-inch diameter (1.5 cfm per linear foot). Filter socks can be stacked on top of one another to increase their flood storage capacity and flow-through rate, and protect against over-topping of water during high flows. Very little field testing has been done with stacked filter socks, so total flow-through rates of stacked socks are not available.

Extent Range Equations:

L(min) = q/4

L(max) = q/1.5

Where L(min) is minimum length in linear feet, L(max) is maximum length in linear feet, and q is flow rate in cubic feet per minute (cfm).

Constructed Wetland Extent Range

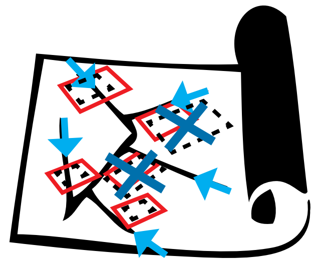
The actual required area of a constructed wetland depends on many factors, including climate, soil type, bed construction material, bed design depth, and constructed wetland design type (Rousseau, 2004). This extent range equation is adapted from Dr. Andrew Wood's "rule of thumb" for areal requirement for constructed wetlands. (Wood, 1995) Based on field studies, Wood estimates that approximately 0.001 to 0.007 hectares of land are required for every cubic meter per day (m^3 -day) of water. Converted to the imperial system of measurement, that translates to approximately 0.1 to 0.7 acres for every cubic foot per minute of water.

Extent Range Equations:

A(min) = q*0.1

A(max) = q*0.7

Where A(min) is minimum surface area in acres, A(max) is maximum surface area in acres, and q is flow rate in cubic feet per minute.



D. Rule out sites and strategies based on extents.

If the estimate for minimum area of vegetated filter is larger than the area of a given site, then rule out vegetated filter for that site.

If the longest topographical line of a given site is less than half the minimum compost filter sock length in linear feet, then rule out this compost filter sock for that site.

If the estimate for minimum area of constructed wetland is larger than the area of a given site, then rule out constructed wetland for that site.

If you have ruled out all of the landscape-based strategies for a given site, rule out that site.

Phase II: Site-scale Analysis

Site-scale analysis is the second phase of the method. This section describes the site variables and cost steps in detail and explains how I developed them based on the research in the previous section.

Step 3. Site Variables

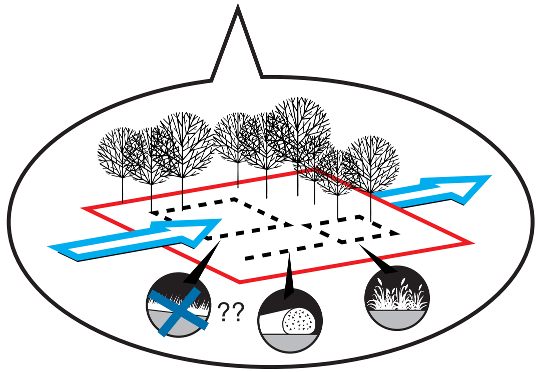
(see worksheet 3 for summary)

The set of questions contained in the site variables step are based on the standard and best practices described in the SWOT analysis of the three example landscape-based strategies. I selected questions for the set based on three factors:

The information or data needed to answer the question can be obtained by an irrigation district in less than one month.

Responses to the questions clearly reflect on the feasibility of each landscape-based method for a site.

The combined questions provide some redundancy, so if all of the questions cannot be answered quickly, a subset of questions will still provide a narrowing-down of options.



E. Rule out strategies based on key site variables.

Site Variable Questions:

a. Is the water source pulse or press?

Pulse water sources provide temporary periods of flow, with dry periods in between. Stormwater is an example of a pulse water source.

Press water sources provide constant inundation, with no dry periods. A perennial creek is an example of a press water source.

Vegetated filters use plant species that cannot tolerate constant inundation (Claytor). They require a pulse water source.

Compost filter socks can handle either type of water source, as long as water doesn't build up to cause overtopping (EPA).

Constructed wetlands, like natural wetlands, use plant species that require constant inundation, and they tend to function less effectively and lose biodiversity with fluctuations in flow. Ideally, they are fed by a press water source. However, a press water source can be simulated by implementing a wet pond for storage and slow release of water from a frequent pulse source (Capiella).

Answer

- If pulse, then constructed wetland is not ideal.
- If press, then compost filter sock and vegetated filter are ruled out.

b. What is the target particle size range at the potential site?

Soil is classified by particle size in different ways by different countries. For the purpose of this method, I will use the United States Department of Agriculture (USDA) classification system:

Fine Clay<0.00005 mm
0.00005<Clay <0.002 mm
0.002<Silt<0.05 mm
0.05<Sand<2.0 mm

(See appendix B for more information on soil classification systems.)

To determine the particle size range, an irrigation district must perform a particle size analysis on a suspended sediment sample derived from the water source that would be filtered on a given potential site. Less accurate estimates of target particle size can be based on the Unified Soil Classification System, which uses visual and tactile analysis to classify soils. *(See appendix B).*

I rated the effectiveness of three example landscape filter strategies to filter fine clay, silt, and sand based on case studies and practitioner reports. I considered a filtration rate of less than 30% to be ineffective, a filtration rate of 31-59% to be effective but not ideal, and a filtration rate of 60% or more to be highly effective.

Vegetated Filter: The estimates below for sediment retention rates in a vegetated filter are based on field studies done on 50 ft wide grass vegetated filters (Abu-Zreig, 2001). Sediment retention tends to increase with increased width, so I consider this a conservative estimated range.

Fine clay: Not measured
Clay: 47%
Silt: 92%
Sand: >92%

Compost Filter: Studies show that the effectiveness of compost filter socks to remove fine suspended particles is tied directly to the grain size of the compost material used, which in turn directly affects the water flow-through rate of the filter. Smaller compost material grain size filters smaller sediment particles, due in part to the resulting slowed flow-through rate. Compost filters have been shown to reduce clay particles up to 65%, silt particles up to 66%, and sand particles up to 99%.

Studies have shown that a significant increase in clay and silt particle retention can be achieved in compost filters by adding a polymer to the filter medium (Faucette , 2006). Initial studies using compost inoculated with mushrooms for compost filters show promising increases in suspended sediment retention, but precise data are not yet available (Brookens et al, 2003).

Fine Clay: Not measured
Clay: 65%
Silt: 66%
Sand: 90%

Constructed Wetland: Case studies of constructed wetlands' effectiveness at filtering suspended sediment vary widely. The following percentages for particle size removal are based on a study of a 0.2 acre constructed wetland (Braskerud, 2003), which is considered a small site. Retention rates for suspended sediment in constructed wetlands tend to go up in relation to area, so I consider this is a conservative estimated range.

Fine Clay: 47%
Clay: 62%
Silt: 76%
Sand: 99%

Answer

- If fine clay, then constructed wetland is effective but not ideal. (No data for other two strategies are available.)
- If clay, then vegetated filter is effective, but not ideal.
- If silt, then no strategies are ruled out or not ideal.
- If sand, then no strategies are ruled out or not ideal.

c. Does the sediment source have concentrated flow or sheet flow?

A concentrated flow of water travels in a narrow area, often in a channel, like a stream. A sheet flow of water travels at an even depth across a flat surface.

Vegetated filters require sheet flow to function. A pea gravel diaphragm can help re-establish a sheet flow, but cannot overcome a strictly concentrated flow (Claytor).

Compost filters can be applied to some light concentrated flow scenarios, but they work best under sheet flow conditions. Concentrated flows can put pressure on the soil supporting the compost filter sock and subsequently cause erosion-based leaks and failures (EPA).

Constructed wetlands can receive some sheet flow water, but they work best with a concentrated source at the point of influence, and a release of treated water at the point of effluence (Capiella).

Answer

- If concentrated, then rule out vegetated filter. Compost filter is possible but not ideal.
- If sheet flow, then constructed wetland is possible but not ideal.

d. What is the slope at the potential site?
Slope is the angle of the ground surface. A perfectly level ground surface has a 0% slope. A ground surface that rises at a 45 degree angle has a 100% slope.

Vegetated filters need at least a 2% slope to move water across their surface. A 2-6% slope is the ideal range for effective suspended sediment removal, and a 6-15% slope, while not ideal, can still be functional. Anything above 15% will function at a diminished rate, if at all (Clar 84).

Compost filter socks can function on a broad range of slopes, but sudden changes or sharply varied topography can make it challenging to fit the filter snugly against the supporting soil (Oregon DEQ, 2004).

Constructed wetlands can be used on sites with an upstream slope of up to approximately 15%. The local slope, however, needs to be relatively shallow, at 1-5%. While there is no minimum slope requirement, there does need to be enough elevation drop from the inlet to the outlet to ensure that hydraulic conveyance by gravity is feasible (generally about 3 to 5 feet difference) (Capiella).

Answer

- If >2%, then rule out vegetated filter and compost sock. Constructed wetland is possible, but not ideal.
- If 2%-5%, then no strategies are ruled out or not ideal.
- If 6%-15%, then rule out constructed wetland. Vegetated filter is possible, but not ideal.
- If 16%-50%, then rule out constructed wetland and vegetated filter.
- If >50% or sharply varied, then rule out all three strategies.

e. What is the soil drainage class at the potential site?
Soil drainage class refers to how quickly water will drain through soil. For the purpose of this method, I use the “Natural Drainage Classes” described in the Natural Resource Conservation Service’s Soil Conservation Manual (see appendix D for soil class descriptions).

Soil classes include:

- Excessively drained.
- Somewhat excessively drained.
- Well drained.
- Moderately well drained.
- Somewhat poorly drained.
- Poorly drained. .
- Very poorly drained.

Vegetated filters require soils that can sustain dense ground-cover vegetation. Ideal soils are well drained or moderately well drained, with an infiltration rate of 0.27 inches per hour or higher. (Clar, 2004, p84)

Compost filters can be used on soils of any drainage class, but excessively and somewhat excessively drained soils will infiltrate water faster than the filter's flow-through rate, thus by-passing the filter. (Faucette)

Constructed wetlands require soils that infiltrate very slowly or not at all, to sustain wetland vegetation. (Capiella) Ideal soils are somewhat poorly drained to very poorly drained.

Answer

- If excessively to somewhat excessively drained, then rule out vegetated filter and constructed wetland. Compost filter is possible, but not ideal.
- If well to moderately well drained, rule out constructed wetland.
- If somewhat to very poorly drained, rule out vegetated filter.

f. What is the depth to the water table at the lowest point of the potential site?

The water table is the level to which water naturally rises at a site. If the water table is below the surface of the soil, then the water on the site is ground water. If the water table is above the surface of the soil, then the water on the site is surface water (wetland, stream, lake, etc).

Vegetated filters require a water table at least two feet below grade to maintain enough air in the soil to support grasses and other upland vegetation (PA DEP).

Compost filters require a water table below grade to function (Faucette).

Constructed wetlands require a water table below grade, as it is not ideal for ground water to mix with the water being treated (Capiella).

Answer

- If above grade or <0 feet below grade, then rule out all example strategies.
- If >0 and <2 feet below grade, then rule out vegetated filter.
- If 2 feet or more below grade, then no strategies are ruled out or not ideal.

g. What is (or can be) the canopy cover at the potential site?

Canopy cover refers to the percentage of ground that is in the shade (usually from trees). Full canopy means that all or almost all of the site is shaded. Partial sum means that some areas are shaded, and some are not. Full sun means that all or almost all of the site is not shaded.

Vegetated filters require partial to full sun in order to support dense ground cover vegetation (Claytor).

Compost filters can function in any land cover scenario, but some vegetation may need to be mowed or cleared to assure proper contact with the ground (EPA).

Constructed wetlands can be built to mimic emergent wetlands, which require full sun, or wooded wetlands, which have some trees and function in partial sun (Capiella).

Answer

- If full canopy, rule out vegetated filter and constructed wetland.
- If partial sun, constructed wetland is possible, but not ideal.
- If full sun, no strategy is ruled out or not ideal.

h. How permanent will the landscape-based strategy need to be?

Some landscape-based strategies are easy to install and remove, while others require considerable labor and expense.

Vegetated filters require precise grading, but otherwise little engineering. They require at least one growing season, and up to five, to establish vegetation. Their overall structure can be built to last if it is well maintained, but can also be altered or removed with relative ease (Claytor).

Compost filter socks clog with sediment after months of use and subsequently require semi-yearly replacement. They can be implemented as a long term solution, but a more permanent structure might be more ideal.

Constructed wetlands require a lot of engineering and are difficult to alter or replace after construction. They are considered a long-term solution.

Answer

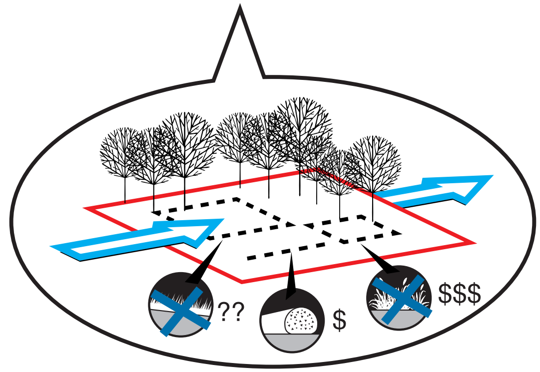
- If short-term removable (1 day to 1 year), then rule out vegetated filter and constructed wetland.
- If long-term removable (1 to 5 years), then rule out constructed wetland
- If permanent (5 to 50 years), then compost filter is possible, but not ideal..

Step 4: Cost
(See worksheet 4 for summary)

Project costs can vary widely by region and by site. Costs that would be considered in a detailed financial feasibility analysis include:

- Land cost
- Design fees (landscape architect, engineer)
- Pre-construction (demolition, cut/fill, access infrastructure)
- Construction hard costs
- Permitting costs
- Habitat mitigation costs
- Financing costs
- Operation costs
- Legal fees
- Field supervision (inspection) costs
- Overhead (staff wages)
- Contingencies
- Maintenance cost
- Monitoring cost
- Alternative uses of land

For the purposes of this method, I have gathered cost range estimates equations for each of the three example landscape-based strategies, that can be calculated using estimated extents.



F. Rule out strategies based on cost range estimates.

Vegetated Filter:
Build: $13,000-$30,000 per acre (EPA)
Maintain: $100-$1400 per acre (PA DEP)

Compost Filter Sock:
Build: $3-$10 per linear foot
Maintain: $0.20-$0.50 per linear foot per year
Source: EPA cost worksheet. To download the Excel file, go to www.epa.gov/wastes/conserve/tools/greenscapes/tools/erosion.pdf)

Constructed Wetland
Build: $38,000-$198,000 per acre (Entrix)
Maintain: $1,300-$9,900 per acre per year (approximately 3-5% of construction cost) (Sample)

Estimate cost ranges and rule out landscape-based strategies that are cost prohibitive.

INTRO TO METHOD WORKSHEETS

This chapter is comprised of a set of worksheets, designed to clarify and streamline the method steps. An irrigation district can use these worksheets to gather and organize district and site data, to rule out potential sites and landscape-based strategies, and to estimate cost and extent ranges. If there are a more than one or two sites being considered, inputting the worksheet equations into an Excel spreadsheet can speed calculations.

SCOPE WORKSHEET *(worksheet 1)*

Information you will need: A district map. Basic understanding of district hydrology and sediment transport.

Suspended Sediment Sources

Some potential sources to consider:

☐ Source: Main water body
Point of entry: Diversion point
Source type: press
Flow type: concentrated

☐ Source: Stormwater
Point of entry: open canal banks
Source type: pulse
Flow type: sheet

☐ Source: Stormwater
Point of entry: stormwater input point
Source type: pulse
Flow type: sheet of concentrated

☐ Source: Irrigation runoff
Point of entry: open canal banks
Source type: pulse or press, depending on irrigation practices
Flow type: sheet

Mark potential sediment sources on the district map.

Potential Build Sites

Some potential sites to consider:

☐ Site: at the diversion.
To intercept: main water body sediment before it enters the system

☐ Site: main canal.
To intercept: canal water sediment before it enters sub-canals.

☐ Site: sub-canals.
To intercept: canal water sediment before it reaches the end user.

☐ Site: canal banks.
To intercept: stormwater or irrigation runoff sediment before it enters the canals.

☐ Site: concentrated stormwater inputs.
To intercept: stormwater sediment before it enters the canals.

☐ Site: end-user draw points.
To intercept: canal water sediment before it reaches sensitive equipment.

Mark potential build sites on the district map.

Site #______

EXTENT WORKSHEET *(worksheet 2)*

Apply the extent step to each potential site.

Information you will need for each potential site:
1) estimated area A =____
2) length along the longest level topography line Lt =____
3) estimated flow rates of water

Flow rate will be specified as either:
maximum flow rate in cubic feet per minute or
designed flow rate in cubic feet per minute

Maximum flow rate:
q = number of cubic feet of water that passes a line perpendicular to the flow of the water, in one minute. Or, volume divided by time.

q = V/T = cubic feet / minute

q = ________

Designed flow rate:
q = volume of design storm in cubic feet, divided by number days release would need to happen multiplied by 1,440 minutes per day. Or, volume divided by time.

q = V/ T days*1440 minutes = V/T = cubic feet per minute

q = ________

Vegetated Filter Extent Range
A(min) = 20*(q/3) = 20*(______/3) = ______
A(max) = 300*(q/3) = 300*(______/3) = _______ (use in cost worksheet)

Where A(min) is minimum required area of vegetated filter in square feet, A(max) is maximum required area of vegetated filter in square feet, and q is flow rate in cubic feet per minute. (Maximum flow rate with a press water source. Peak flow rate with a pulse water source.)

If the estimate for minimum area of vegetated filter is larger than the usable area of a given site, then rule out this landscape-based strategy for that site.

Ruled out?: Y / N

Compost Sock Extent Range
L(min) = q/4 = _____ /4 = ______
L(max) = q/1.5 = _____ /1.5 = ______ (use in cost worksheet)

Where L(min) is minimum length in linear feet, L(max) is maximum length in linear feet, and q is flow rate, in cubic feet per minute (cfm). (Maximum flow rate with a press water source. Peak or design flow rate with a pulse water source.)

If the longest level topography line (Lt) of a given site is less than half of the minimum compost sock length in linear feet, then rule out this landscape-based strategy for that site.

Ruled out?: Y / N

Constructed Wetland Extent Range
A(min) = q*0.1 = _____*0.1 = ______
A(max) = q*0.7 = _____ *0.7 = ______ (use in cost worksheet)

Where A(min) is minimum surface area in acres, A(max) is maximum surface area in acres, and q is flow rate in cubic feet per minute. (Maximum flow rate with a press water source. Peak or design flow rate with a pulse water source.)

If the estimate for minimum area of constructed wetland is larger than the usable area of a given site, then rule out this landscape-based strategy for that site.

Ruled out?: Y / N

SITE VARIABLES WORKSHEET *(worksheet 3)*

FILTER TYPE	OPTIONS	FEASIBILITY V VEGETATED FILTER	C COMPOST FILTER	W CONSTRUCTED WETLAND	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	SITE 9
Is water source pulse or press?	Pulse	●	●	◒									
	Press	○	◒	●									
What is the target particle size range?	Fine Clay < 0.00005 mm	?	?	◒									
	0.00005 < Clay < 0.002 mm	◒	●	●									
	0.002 < Silt < 0.05 mm	●	●	●									
	0.05 < Sand < 2.0 mm	●	●	●									
Does the sediment source have concentrated flow or sheet flow?	Concentrated	○	◒	●									
	Sheet	●	●	◒									
What is the slope at the potential site?	< 2%	○	○	◒									
	2 – 5%	●	●	●									
	6 – 15%	◒	●	○									
	16 – 50%	○	●	○									
	> 50% or sharply varied	○	○	○									
What is the soil drainage class at the potential site?	Somewhat to very excessively drained	○	◒	○									
	Well to moderately well drained	●	●	○									
	Somewhat to very poorly drained	○	●	●									
What is the depth to the water table at the lowest point of the potential site?	< 0 feet	○	○	○									
	0-2 feet	○	●	●									
	> 2 feet	●	●	●									
What is (or will be) the canopy cover at the potential site?	Full canopy	◒	●	○									
	Partial sun	●	●	◒									
	Full Sun	●	●	●									
How permanent will the landscape-based strategy need to be?	Short-term removable (1 day to 1 year)	○	●	○									
	Long-term removable (1 to 5 years)	●	◒	○									
	Permanent (5 to 50 years)	●	◒	●									
				Results:									

Apply the site variables step to each remaining potential site.

● **DO NOT RULE OUT**

◒ **NOT IDEAL**

○ **RULE OUT**

V = Vegetated filter is ruled out

v = Vegetated filter is not ideal

C = Compost filter is ruled out

c = Compost filter is not ideal

W = Con. wetland is ruled out

w = Con. wetland is not ideal

none = no landscape-based strategy is ruled out

Site #______

COST WORKSHEET *(worksheet 4)*

Apply the cost step to each remaining potential site and landscape-based strategy combination.

Information you will need for each potential site and landscape-based strategy combination:
1) estimated extent range

Vegetated Filter Extent = (min)________ to (max)________

Compost Filter Extent = (min)________ to (max)________

Constructed Wetland Extent = (min)________ to (max)________

2) number of years the landscape strategy will need to function

years = ________

Vegetated Filter Cost Range:
Build: $13,000-$30,000 per acre
Maintenance: $100-$1400 per acre, first 5 years

Min Build Cost = Min Extent in acres * $13,000

= ______* $13,000 = ______ ○

Max Build Cost = Max Extent in acres * $30,000

= ______* $30,000 = ______ □

Min Maint Cost = Min Extent in acres * $100 * 5 years

= ______* $100 * 5 = ______ △

Max Maint Cost = Max Extent in acres * $1400 * 5 years

= ______* $1400 * 5 = ______ ◇

Min Build/Maint cost = Min Build Cost + Min Maint Cost

= ______ ○ + ______ △ = ______ **$**

Max Build & Maint cost = Max Build Cost + Max Maint Cost

= ______ □ + ______ ◇ = ______ **$$$**

Cost Range = ______ **$** to ______ **$$$**

Site #______

Compost Filter Sock Cost Range:
Build: $3-$10 per linear foot
Maintain: $0.20-$0.50 per linear foot per year

Min Build Cost = Min Extent in linear ft * $3

= _______* $3 = _______
○

Max Build Cost = Max Extent in linear ft * $10

= _______* $10 = _______
□

Min Maint Cost = Min Extent in linear ft * $0.20 * # of years

= _______* $0.20 * ______= _______
△

Max Maint Cost = Max Extent in linear ft * $0.50 * # of years

= _______* $0.50 * ______= _______
◇

Min Build & Maint cost = Min Build Cost + Min Maint Cost

= _______ + _______ = _______
○ △ **$**

Max Build & Maint cost = Max Build Cost + Max Maint Cost

= _______ + _______ = _______
□ ◇ **$$$**

Cost Range = _______ to _______
$** **$$$

Constructed Wetland Cost Range:
Build: $38,000-$198,000 per acre
Maintain: $1,300-$9,900 per acre per year

Min Build Cost = Min Extent in acres * $38,000

= _______* $38,000 = _______
○

Max Build Cost = Max Extent in acres * $198,000

= _______* $198,000 = _______
□

Min Maint Cost = Min Extent in acres * $1,300 * # of years

= _______* $1,300 * ______= _______
△

Max Maint Cost = Max Extent in acres * $9,900 * # of years

= _______* $9,900 * ______= _______
◇

Min Build & Maint cost = Min Build Cost + Min Maint Cost

= _______ + _______ = _______
○ △ **$**

Max Build & Maint cost = Max Build Cost + Max Maint Cost

= _______ + _______ = _______
□ ◇ **$$$**

Cost Range = _______ to _______
$** **$$$

INTRO TO METHOD APPLICATION AND RESULTS

To test the newly developed method, I applied it to the Farmers Irrigation District (FID) of Hood River with input from their staff. I used data that FID had generated previously for unrelated projects and collected data with online tools including the Hood River County WebMap, Google Maps,™ and the Soil Survey of Hood River County, Oregon. I entered the method worksheet equations into Excel spreadsheets to speed the calculation process.

METHOD APPLICATION AND RESULTS

Phase 1: Landscape-Scale Analysis

Step 1. Scope

(See worksheet 1.1 and figure 9)

To complete the scope step of the method, I used a district map and input from FID staff to identify potential sources for suspended sediment in the FID system as well as potential build sites for landscape-based strategies.

A. Suspended Sediment Sources: Where is sediment entering the system?
FID staff identified diversion water and stormwater inputs as the two main potential source types for suspended sediment in their system. The water flowing down Hood River off of Mt. Hood carries particles that are volcanic in origin. The water entering nine stormwater inputs managed by FID contains topsoil washed from agricultural fields during storm events. Six out of the nine inputs (Draws 1, 2, 3, 4, 6, and 7) input water to the Farmers Canal. The remaining three inputs (Draws 5, 8, and 9) bypass the canal system and are released into Hood River. *(See appendix E for a sub-basin map for the stormwater inputs.)*

Most of the FID canal system is piped, and the segments that aren't piped are in forested areas, so stormwater and irrigation runoff entering the canals through open banks is not a significant issue.

Sources Results
I used black dots to mark the eight potential suspended sediment sources on the district map *(see figure 9)*.

B. Potential Sites: Where might strategies be built?
FID staff suggested that the diversion water could be filtered either at the diversion site, or downstream at a site near Pine Creek. Either of these sites would position the landscape-based strategy to intercept suspended sediment before the diversion water enters the piped canal system.

Using FID's map of the stormwater input sub-basins, I chose sites that would intercept stormwater just before it enters the inputs. I assumed the sites would encompass 5% of the total area of each sub-basin, based on the EPA's best management practice for stormwater wetlands that estimates their required extent to be about 3-5% of the drainage area. Stormwater wetlands tend to have the largest extent requirement out of the three example landscape-based strategies, so 5% seemed to be a generous area against which I could compare extent estimates.

Sites Results
I used red stars to mark the Hood River diversion site, Pine Creek site, and seven stormwater input sites (Draw 1, 2, 3, 4, 6, 7; Portland Rd) on the district map *(see figure 9)*.

SCOPE WORKSHEET *(worksheet 1.1)*

Information you will need: A district map. Basic understanding of district hydrology and sediment transport.

Suspended Sediment Sources

Some potential sources to consider:

- [x] Source: Main water body
  Point of entry: Diversion point
  Source type: press
  Flow type: concentrated

- [ ] Source: Stormwater
  Point of entry: open canal banks
  Source type: pulse
  Flow type: sheet

- [x] Source: Stormwater
  Point of entry: stormwater input point
  Source type: pulse
  Flow type: sheet of concentrated

- [ ] Source: Irrigation runoff
  Point of entry: open canal banks
  Source type: pulse or press, depending on irrigation practices
  Flow type: sheet

Mark potential sediment sources on the district map.

Potential Build Sites

Some potential sites to consider:

- [x] Site: at the diversion.
  To intercept: main water body sediment before it enters the system

- [x] Site: main canal.
  To intercept: canal water sediment before it enters sub-canals.

- [ ] Site: sub-canals.
  To intercept: canal water sediment before it reaches the end user.

- [ ] Site: canal banks.
  To intercept: stormwater or irrigation runoff sediment before it enters the canals.

- [x] Site: concentrated stormwater inputs.
  To intercept: stormwater sediment before it enters the canals.

- [ ] Site: end-user draw points.
  To intercept: canal water sediment before it reaches sensitive equipment.

Mark potential build sites on the district map.

FARMERS IRRIGATION DISTRICT OF HOOD RIVER

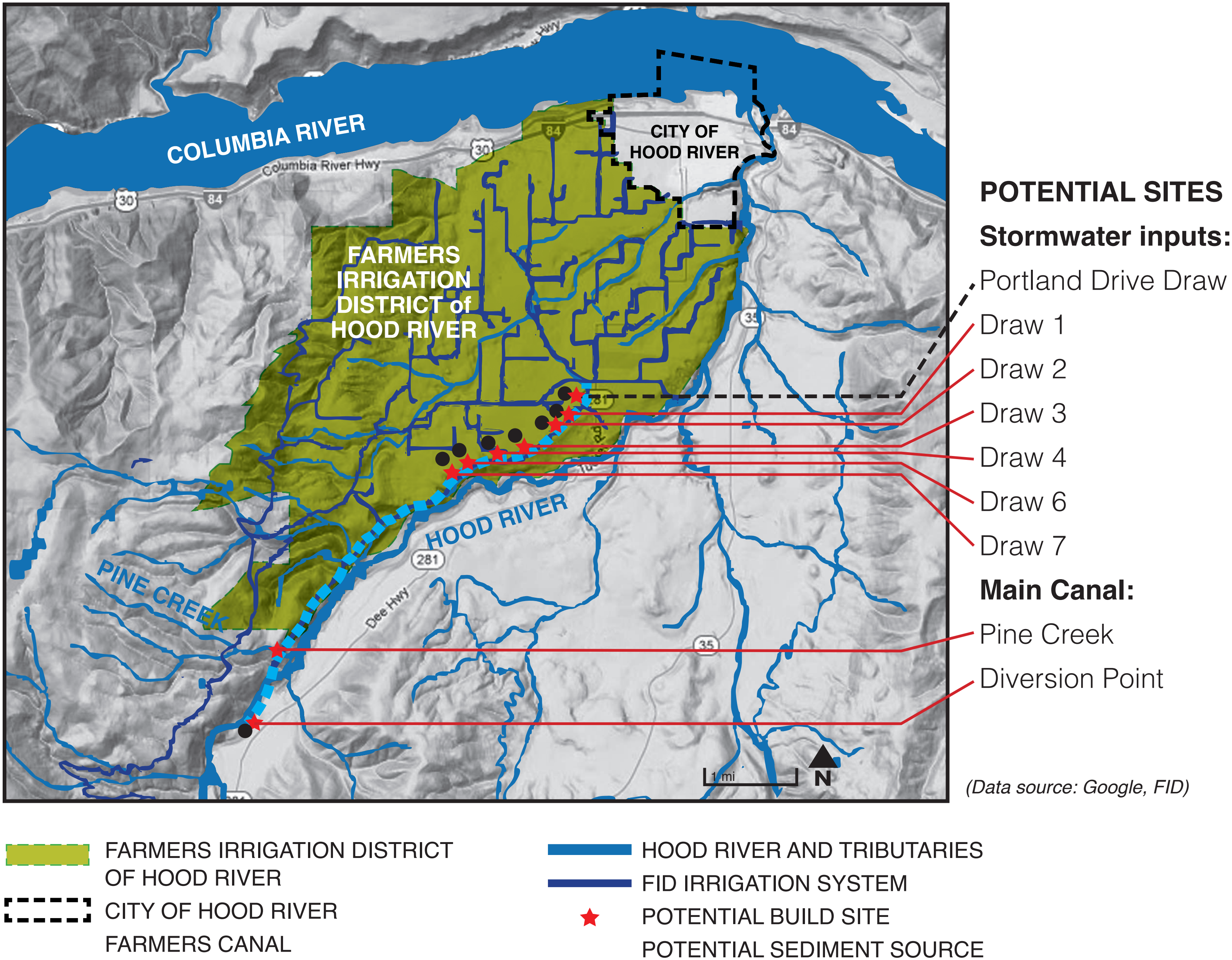


Figure 9. FID Scope Map

Step 2. Extent

(See worksheet 2.1 and figure 12 for an illustrative example)

To complete the extent step, I used the flow rates of water for each potential site to find an estimated range of extent for the landscape-based strategies at each potential site. Using an Excel table, I compared the landscape-based strategy extents with the site areas and lengths along longest topography lines to rule out any strategy that would be too large for a site, or to rule out any site that would be too small for all of the strategies.

Areas: For the stormwater input sites, FID staff provided me with an Excel data table that included the area of land in each sub-basin. I calculated 5% of the total areas to estimate site areas (See table . To estimate site areas for the Hood River diversion and Pine Creek, I used the area measure tool in Hood River County WebMap *(see the Pine Creek site example in figure 10)*.

Topography Lines: To estimate the longest topography line on each site, I used the length measure tool in Hood River County Webmap *(an example from the Hood River diversion sites is pictured in figure 11)*.

Flow Rates: FID staff provided me with the peak flow rate at the Hood River Diversion and an Excel data table that included the peak flow rates for each of the stormwater inputs during a 100 year, 50 year, 5 year, and 2 year storm event.

I based extent range estimates for the Hood River diversion and Pine Creek sites on the peak flow rate of the Hood River diversion, which is 4380 cfm. I used an Excel spreadsheet to calculate extent ranges *(See appendix F)*.

Based on EPA recommendations, I based extent range estimates for the stormwater input sites on peak flow rates during a 2 year design storm or 30-day release flow rates based on total volume of runoff during a 2 year design storm.

I used the Excel spreadsheet to calculate the total design storm volume based on the runoff depth in inches and drainage area in acres for each sub-basin, provided by FID, and then converted acre inches to cubic feet by multiplying by 3630 (number of cubic feet in an acre inch) *(See appendix F)*.

$$V = D * A * 3630$$

Where V is the total volume of the design storm in cubic feet, D is the runoff depth in inches, A is the drainage area in acres, and 3630 is number of cubic feet per acre inch.

I divided each total volume by the number of minutes contained in 30 days (43,200) to get flow rate in cubic feet per minute.

Extent Results

After using an Excel table to employ the estimated extent equations from the extent worksheet, I compared the resulting minimum extent with the estimated site areas (see table 4). I ruled out constructed wetlands as an option for the Hood River Diversion and Pine Creek potential sites, as the minimum extent for this landscape-based strategy greatly exceeds the site area. I did not rule out any landscape-based strategies for the stormwater input potential sites.

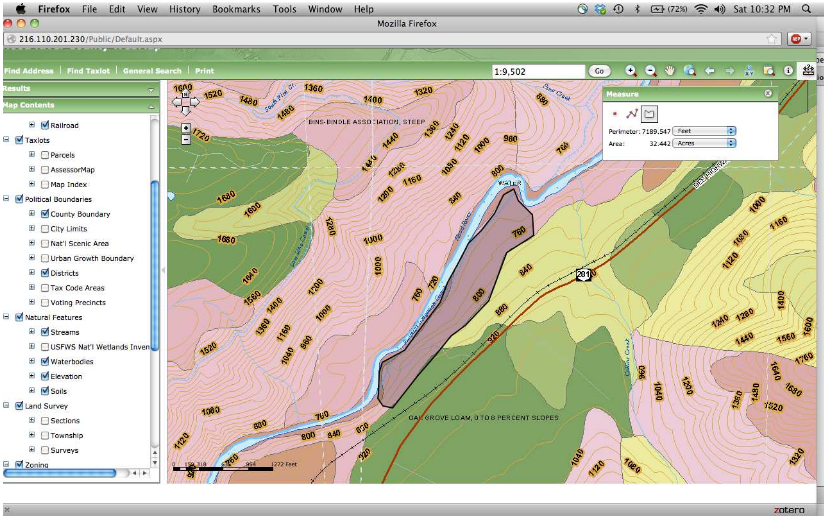


Figure 10. Area measurement of the Hood River Diversion site using the Hood River County WebMap tool.

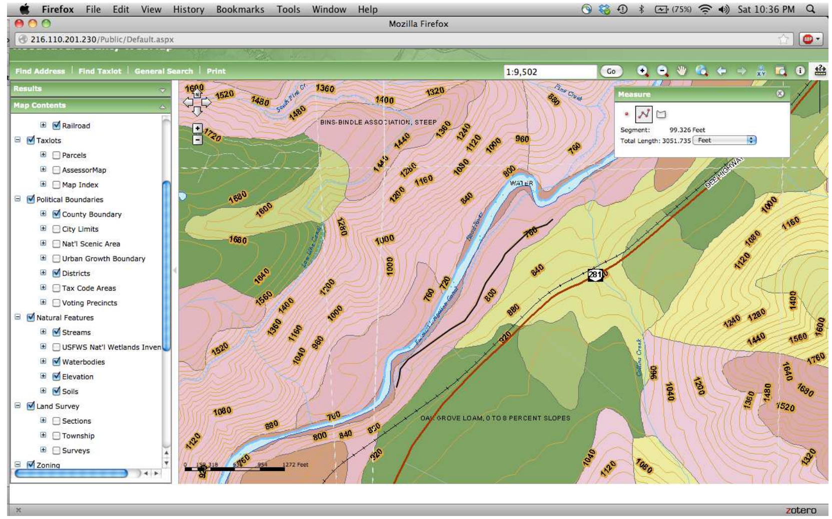


Figure 11. Longest topography line measurement of the Hood River Diversion site using the Hood River County WebMap tool.

FARMERS IRRIGATION DISTRICT, FARMERS CANAL PIPELINE, 2-YEAR STORM EVENT SUBBASIN REPORT, 2013

Provided by FID							Calculated by Author		
Element ID	**Area (A) (acres)**	**Average Slope (%)**	**Time of Concentration (days hh:mm:ss)**	**Total Precipitation (inches)**	**Total Runoff (inches)**	**Peak Runoff R (cfs)**	**Peak Runoff R*60 (cfm)**	**Design Storm Volume (V) A*D*3630 (cubic feet)**	**Flow rate if released over 30 days V/(30*24*60) (cfm)**
Draw 1	8.92	6.6000	0 00:13:39	1.99	0.31	0.19	11.4	10037.68	0.23
Draw 2	54.41	5.4000	0 00:20:40	1.99	0.31	1.13	67.8	61227.57	1.42
Draw 3	51.79	6.0000	0 00:20:47	1.99	0.31	1.07	64.2	58279.29	1.35
Draw 4	34.45	9.0000	0 00:18:17	1.99	0.31	0.71	42.6	38766.59	0.90
Draw 6	18.08	7.0000	0 00:15:39	1.99	0.31	0.37	22.2	20345.42	0.47
Draw 7	42.09	7.0000	0 00:23:08	1.99	0.31	0.87	52.2	47363.88	1.10
Portland Drive	73.53	4.2000	0 00:23:01	1.99	0.31	1.52	91.2	82743.31	1.92

Table 6. Farmers Irrigation District, Farmers Canal Pipeline, 2-Year Storm Event Subbasin Report, 2013

Site # 1

EXTENT WORKSHEET *(worksheet 2.1)*

Apply the extent step to each potential site.

Information you will need for each potential site:
1) estimated area A = 3.68 ac.
2) length along the longest level topography line Lt = 644 ft
3) estimated flow rates of water

Flow rate will be specified as either:
maximum flow rate in cubic feet per minute or
designed flow rate in cubic feet per minute

Maximum or Peak flow rate:
q = number of cubic feet of water that passes a line perpendicular to the flow of the water, in one minute. Or, volume divided by time.

q = V/T = cubic feet / minute

q = 91.2 cfm

Designed flow rate:
q = volume of design storm in cubic feet, divided by number days release would need to happen multiplied by 1,440 minutes per day. Or, volume divided by time.

q = V/ T days*1440 minutes = V/T = cubic feet per minute

q = 82743.31 cf / 30 days * 1440 = 1.92 cfm

Vegetated Filter Extent Range
A(min) = 20*(q/3) = 20*(91.2 cfm /3) = 608 sf or 0.014 acres
A(max) = 300*(q/3)= 300*(91.2 cfm /3) = 9120 sf or 0.209 acres
(use in cost worksheet)

Where A(min) is minimum required area of vegetated filter in square feet, A(max) is maximum required area of vegetated filter in square feet, and q is flow rate in cubic feet per minute. (Maximum flow rate with a press water source. Peak flow rate with a pulse water source.)

If the estimate for minimum area of vegetated filter is larger than the usable area of a given site, then rule out this landscape-based strategy for that site.

Ruled out?: Y / (N)

Compost Sock Extent Range
L(min) = q/4 = 91.2 cfm /4 = 22.8 f
L(max) = q/1.5 = 91.2 cfm /1.5 = 60.8 f (use in cost worksheet)

Where L(min) is minimum length in linear feet, L(max) is maximum length in linear feet, and q is flow rate, in cubic feet per minute (cfm). (Maximum flow rate with a press water source. Peak flow rate with a pulse water source.)

If the longest level topography line (Lt) of a given site is less than half of the minimum compost sock length in linear feet, then rule out this landscape-based strategy for that site.

Ruled out?: Y / (N)

Constructed Wetland Extent Range
A(min) = q*0.1 = 1.92 cfm*0.1 = 0.192 ac.
A(max) = q*0.7 = 1.92 cfm*0.7 = 1.341 ac. (use in cost worksheet)

Where A(min) is minimum surface area in acres, A(max) is maximum surface area in acres, and q is flow rate in cubic feet per minute. (Maximum flow rate with a press water source. Design flow rate with a pulse water source.)

If the estimate for minimum area of constructed wetland is larger than the usable area of a given site, then rule out this landscape-based strategy for that site.

Ruled out?: Y / (N)

POTENTIAL SITE 1: PORTLAND ROAD

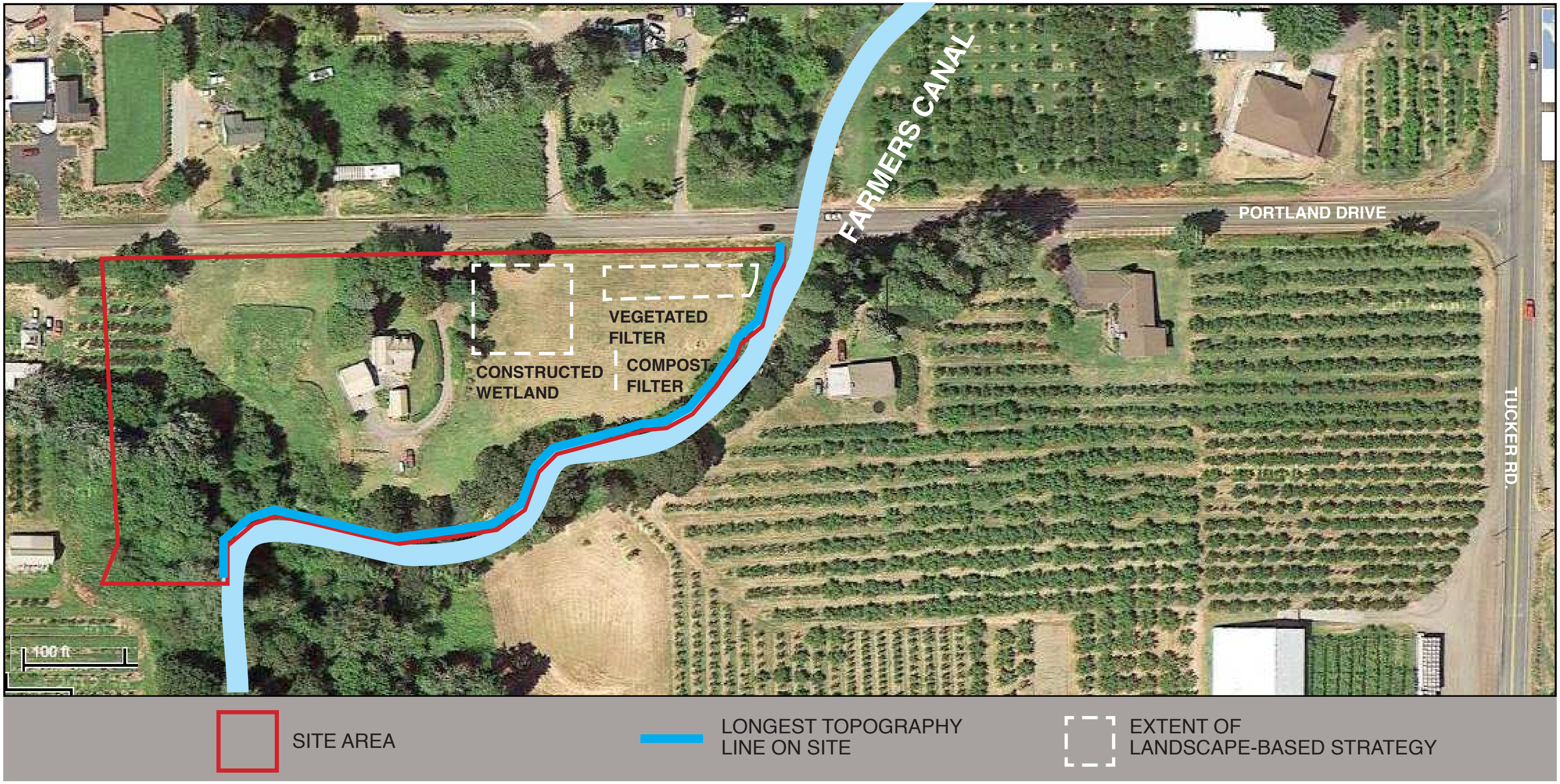


Figure 12. Extent map of potential site 1: Portland Road

Phase II: Site-scale Analysis

Step 3. Site Variables

I used data provided by FID and information I gathered from the Hood River County WebMap, Google Maps,™ and the Soil Survey of Hood River County, Oregon to answer questions on the site variables worksheet. Supporting information is in regular type.

Site Variable Questions

a. Is the water source pulse or press?

A river diversion is a press source.

This rules out vegetated filters as a strategy for the Hood River Diversion and Pine Creek sites.

Stormwater is a pulse source.

This means constructed wetlands are possible but not ideal for the stormwater input sites.

b. What is the target particle size range at the potential site?

FID was unable to provide me with a sample or a particle size analysis of their suspended sediment, but were able to provide me with a sample of the sediment that they are currently able to remove with mechanical filters. Using the Unified Soil Classification System, I classified the soil sample as “poorly graded sand with silt.” I assumed that the target particle range for FID is smaller than the sediment they are effectively able to filter, and indicated silt and clay on the worksheet. When FID can determine a more precise target particle range, they can edit this part of the worksheet to reflect greater accuracy.

The inclusion of clay target particle sizes means that vegetated filters are considered effective but not ideal. The inclusion of silt target particle sizes does not rule out any landscape-based strategies.

c. Does the sediment source have a concentrated flow or sheet flow?

The Hood River diversion source has a concentrated flow.

This rules out vegetated filters and means that compost filters are considered possible but not ideal at the Hood River diversion and Pine Creek sites.

The stormwater inputs have sheet flow until they are concentrated to enter the input point.

This means that constructed wetlands are considered possible but not ideal for all six of the stormwater input sites.

d. What is the slope at the potential site?

I used the length measure tool in Hood River WebMap to estimate the distance between 40 ft topography lines on each site *(see figure 13 for an example)*, and divided that distance by 40 to estimate slope *(see table 5)*. All of the potential sites fall into either the 5-15% or 15-50% slope ranges.

A slope of 5-15% rules out constructed wetlands and means that vegetated filters are considered possible but not ideal. A slope of 15-50% rules out constructed wetlands and vegetated filters.

SLOPE BY SITE

	slope
Portland Rd	6.50%
Draw 1	12%
Draw 2	17%
Draw 3	19%
Draw 4	17%
Draw 6	40%
Draw 7	40%
Pine Creek	11%
Hood River Diversion	17%

Table 7. Slope by site

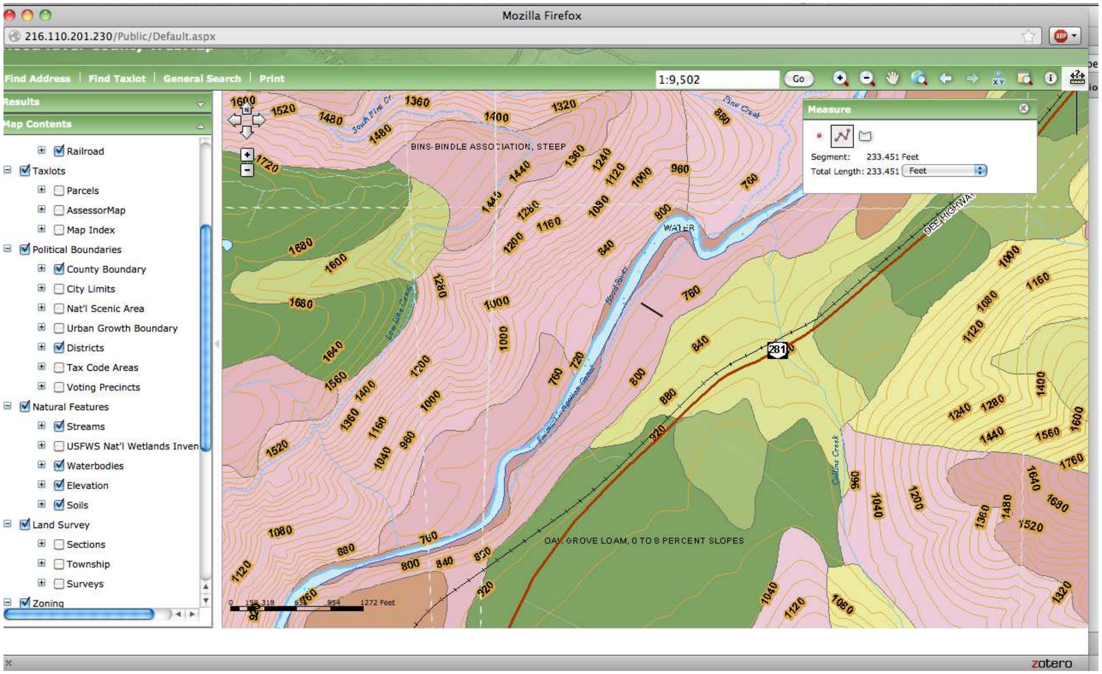


Figure13. Slope length measurement of the Hood River Diversion site using the Hood River County WebMap tool.

e. What is the soil drainage class at the potential site?
I used Hood River WebMap to identify the soil series and phase at each site and used descriptions of each soil series in the Soil Survey of Hood River County, Oregon to determine the soil drainage class. Soils are well drained at all of the potential sites except stormwater input Draw 1, which is somewhat poorly drained.

This rules out vegetated filter as a strategy for the Draw 1 site, and rules out constructed wetland as a strategy for all other sites.

f. What is the depth to the water table at the lowest point of the potential site?
I used the Soil Survey of Hood River County, Oregon to determine the depth to water table for each soil series and phase. All sites have water table depths of more than 5 feet except for stormwater input Draw 1, which has a water table depth of 1-2 feet.

This rules out vegetated filter as a strategy for the Draw 1 site.

g. What is (or can be) the land cover at the potential site?
I used aerial photos in Google Maps ™ to determine the land cover at each potential site. All sites fell into the partial sun or full canopy categories.

For potential sites with full canopy (Draw 6 and 7, and Pine Creek), this rules out constructed wetland as a strategy and means that vegetated filter is considered possible but not ideal. For potential sites with partial sun (Portland Road, Draws 1-4, and the Hood River diversion), this means that constructed wetland is considered possible but not ideal.

h. How permanent will the landscape-based strategy need to be?
Based on FID input, I categorized landscape-based strategies for all potential sites as permanent (5-50 years).

This means that compost filters are considered possible but not ideal for all potential sites.

Site Variable Results
I noted my results for each question on the site variable worksheet, using capital letters to denote the ruling out of landscape-based strategies and lower case to denote that landscape-based

SITE VARIABLES WORKSHEET *(worksheet 3.1)*

FILTER TYPE	OPTIONS	V VEGETATED FILTER	C COMPOST FILTER	W CONSTRUCTED WETLAND	PORTLAND RD SITE 1	DRAW 1 SITE 2	DRAW 2 SITE 3	DRAW 3 SITE 4	DRAW 4 SITE 5	DRAW 6 SITE 6	DRAW 7 SITE 7	PINE CREEK SITE 8	DIVERSION SITE 9
		FEASIBILITY											
Is water source pulse or press?	Pulse	●	●	◒	w	w	w	w	w	w	w		
	Press	○	◒	●								Vc	Vc
What is the target particle size range?	Fine Clay < 0.00005 mm	?	?	◒	?	?	?	?	?	?	?	?	?
	0.00005 < Clay < 0.002 mm	◒	●	●	v	v	v	v	v	v	v	v	v
	0.002 < Silt < 0.05 mm	●	●	●	none	none	none	none	none	none	none	none	none
	0.05 < Sand < 2.0 mm	●	●	●	?	?	?	?	?	?	?	?	?
Does the sediment source have concentrated flow or sheet flow?	Concentrated	○	◒	●								Vc	Vc
	Sheet	●	●	◒	w	w	w	w	w	w	w		
What is the slope at the potential site?	< 2%	○	○	◒									
	2 – 5%	●	●	●									
	6 – 15%	◒	●	○	vW	vW						vW	
	16 – 50%	○	●	○			VW	VW	VW	VW	VW		VW
	> 50% or sharply varied	○	○	○									
What is the soil drainage class at the potential site?	Somewhat to very excessively drained	○	◒	○									
	Well to moderately well drained	●	●	○	W		W	W	W	W	W	W	W
	Somewhat to very poorly drained	○	●	●		V							
What is the depth to the water table at the lowest point of the potential site?	< 0 feet	○	○	○									
	0-2 feet	○	●	●		V							
	> 2 feet	●	●	●	none		none	none	none	none	none	none	none
What is (or will be) the canopy cover at the potential site?	Full canopy	◒	●	○						vW	vW	vW	
	Partial sun	●	●	◒	w	w	w	w	w				w
	Full Sun	●	●	●									
How permanent will the landscape-based strategy need to be?	Short-term removable (1 day to 1 year)	○	●	○									
	Long-term removable (1 to 5 years)	●	◒	○									
	Permanent (5 to 50 years)	●	◒	●	c	c	c	c	c	c	c	c	c
	Results:				vcW	VcW	VcW	VcW	VcW	VcW	VcW	VcW	VcW

Apply the site variables step to each remaining potential site.

● **DO NOT RULE OUT**

◒ **NOT IDEAL**

○ **RULE OUT**

V = Vegetated filter is ruled out

v = Vegetated filter is not ideal

C = Compost filter is ruled out

c = Compost filter is not ideal

W = Con. wetland is ruled out

w = Con. wetland is not ideal

none = no landscape-based strategy is ruled out strategies were possible but not ideal. (V or v for vegetated filter, C or c for compost filter, and W or w for constructed wetland.)

I ruled out vegetated filters based on press water source and concentrated flow for both of the diversion source potential sites. I ruled out vegetated filters based on slope above 15% for five of the seven stormwater input sites (Draws 2, 3, 4, 6, and 7). I ruled out constructed wetlands based on site constraints for all seven stormwater input sites. I found that compost filter sock is possible but not ideal for all potential sites, and vegetated filter is possible but not ideal for the Portland Road stormwater input site.

Step 4. Cost

I estimated cost ranges for the “possible but not ideal” strategies. I found that implementation of compost filter socks could be either very cost-effective (under $100 per year for stormwater sites) or moderately cost-effective (under $4000 per year for diversion sites) for a 10 year period. I found that a vegetated filter could be moderately cost-effective (under $1000 per year) for the Portland Road stormwater site.

Portland Road Site Vegetated Filter

To calculate a cost range estimate for a vegetated filter at the Portland Road stormwater input site, I inputted the estimated extent range I generated in the extent step, and the cost range data indicated on the cost estimate worksheet into an Excel table *(see worksheet 4.1 for a cost worksheet example, and appendix G for a table of all cost estimates)*.

I multiplied the site’s vegetated filter minimum extent (in acres) with the vegetated filter minimum build cost per acre to find the minimum build cost for the project. I multiplied the site’s vegetated filter maximum extent (in acres) with the vegetated filter maximum build cost per acre to find the maximum build cost for the project. I multiplied the minimum and maximum maintenance cost per acre by the minimum and maximum extent, and then multiplied both by 10 to find the minimum and maximum maintenance cost for the project. I added the minimum build cost to the minimum maintenance cost and added the maximum build cost to the maximum maintenance cost to find a minimum and maximum total build and maintenance cost for the project.

Compost Filter Sock for All Potential Sites

To calculate a cost range estimate for compost filter socks at all potential sites, I inputted the estimated extent ranges I generated in the extent step, and the cost range data indicated on the cost estimate worksheets into an Excel table *(see appendix G for a table of all cost estimates)*.

I multiplied the sites’ compost filter minimum extent (in linear feet) with the compost filter minimum build cost per linear foot to find the minimum build cost for each project. I multiplied the site’s compost filter maximum extent (in linear feet) with the compost filter maximum build cost per linear foot to find the maximum build cost for each project. I multiplied the minimum and maximum maintenance cost per linear foot by the minimum and maximum extent, and then multiplied both by 10 to find the minimum and maximum maintenance costs for each project. I added the minimum build costs to the minimum maintenance costs and added the maximum build costs to the maximum maintenance costs to find a minimum and maximum total build and maintenance cost for each project.

COST WORKSHEET *(worksheet 4.1)*

Apply the cost step to each remaining potential site and landscape-based strategy combination.

Information you will need for each potential site and landscape-based strategy combination:
1) estimated extent range

Vegetated Filter Extent = (min) 0.014 acres to (max) 0.209 acres

Compost Filter Extent = (min)_______ to (max)_______

Constructed Wetland Extent = (min)_______ to (max)_______

2) number of years the landscape strategy will need to function

years = 10

Site # 1

Vegetated Filter Cost Range:
Build: $13,000-$30,000 per acre
Maintenance: $100-$1400 per acre, first 5 years

Min Build Cost = Min Extent in acres * $13,000

= 0.014 ac. * $13,000 = $181.45 ○

Max Build Cost = Max Extent in acres * $30,000

= 0.209 ac. * $30,000 = $6,280.99 □

Min Maint Cost = Min Extent in acres * $100 * 5 years

= 0.014 ac. * $100 * 5 = $13.96 △

Max Maint Cost = Max Extent in acres * $1400 * 5 years

= 0.209 ac. * $1400 * 5 = $2,931.13 ◇

Min Build/Maint cost = Min Build Cost + Min Maint Cost

= $181.45 (○) + $13.96 (△) = $195.41 **$**

Max Build & Maint cost = Max Build Cost + Max Maint Cost

= $6,280.99 (□) + $2,931.13 (◇) = $9,212.12 **$$$**

Cost Range = $195.41 (**$**) to $9,212.12 (**$$$**)

Final Method Results

Vegetated Filter at the Portland Road Stormwater Inlet

A vegetated filter may be a feasible, moderately cost effective (under $1000 per year) landscape-based strategy to filter suspended sediment at the Portland Road stormwater input site in the Farmers Irrigation District of Hood River. However, this potential site and landscape-based strategy combination may not be ideal, due to the site's 5-15% slope and a target particle size in the clay range. These variables should be considered in subsequent field testing.

Compost Filter Sock at All Stormwater Input Sites

A compost filter sock may be a feasible, very cost effective (under $100 per year) landscape-based strategy to filter suspended sediment at all stormwater input sites (Draw 1, 2, 3, 4, 6, and 7 and Portland Road) in the Farmers Irrigation District of Hood River. However, these potential site and landscape-based strategy combinations may not be ideal, due to the desire for a more permanent solution. This should be considered in subsequent field testing.

Compost Filter Sock at Hood River Diversion and Pine Creek Sites

A compost filter sock may be a feasible, moderately cost effective (under $4000 per year) landscape-based strategy to filter suspended sediment at both diversion water sites in the Farmers Irrigation District of Hood River. However, this potential site and landscape-based strategy combination may not be ideal, due to the press source and concentrated flow of water, and the desire for a more permanent solution. This should be considered in subsequent field testing.

INTERPRETING RESULTS

In this section I will briefly reflect on key findings of this project.

Research Question

This project aims to answer the question:

What is a transferable method to determine whether landscape-based strategies might be feasible sediment filtration solutions for irrigation districts to field test?

The method I developed as an answer to this question is by no means the only possible method. It applies concepts that are common in landscape architecture and planning, including site selection, site analysis, and cost analysis. It considers the scope of the irrigation district's suspended sediment problem, the necessary extents of the landscape-based strategies, specific site variables, and potential cost of the project. It is a subtractive process—it saves time by ruling out sites and strategies that are not feasible based on available information, so irrigation districts can concentrate energy on the most feasible options.

The components I would argue are key to creating a transferable method to solve this problem include:

Landscape-scale analysis: This step allows practitioners of the method to consider the problem at a system scale—the variety of ways sediment might be entering the system, and the various points in the system at which sediment might be filtered out.

Site-scale analysis: This step allows practitioners to consider the specific conditions that might affect the feasibility of a landscape-based strategy at a particular site.

Extent: Landscape-based strategies must be sized according to the flow rate of water they are designed to treat. Some strategies require significant retention times to treat water, which translates to prohibitive extents as flow rates rise. Extent is a key factor of feasibility, and should be considered early in the method process.

Target particle size: Particle size is potentially the most important feasibility factor to consider. If landscape-based solutions cannot effectively reduce particles in the target size range, then no other factors matter.

I had difficulty finding literature to support filtration effectiveness in terms of particle size for the three example landscape-based strategies. The data I did find are based on limited studies. As research toward solving the problem of suspended sediment moves forward, it is essential that more precise study is done on how effectively landscape-based strategies filter specific particle sizes.

Multiple landscape-based strategies: A successful transferable method will allow irrigation districts to consider a variety of landscape-based strategies, and will help practitioners to narrow down those strategies to the most feasible options.

Cost: While all of the other key factors help to determine whether a landscape-based strategy *can* be applied to a site, the cost step helps to determine whether it *should* be applied. The cost effectiveness of these strategies should be compared to that of more highly engineered solutions.

Method Goals

My goals for the method included ease of use. I defined ease of use through three concepts: fast, easy, and step by step.

Fast: The method was fast. Applying the method took a total of six hours. Collecting data from FID took less than 30 days, except for the particle size data, which we were not able to collect.

Easy: The method was easy. I applied, it, and I'm certainly no hydrologist or engineer. The math was simple, and could be made easier with the help of Excel spreadsheets. These spreadsheets should be added to the worksheets to aid in application of the method. The tools I used (GoogleMaps, Hood River County WebMap, Hood River Area Soil Survey) were easy to employ and widely available.

Step-by-step: The method could use further simplification in terms of its sub-steps. The worksheets helped me to know what data I needed, but not always how to collect it. The method followed a logical progression, but the site variable questions, for example, could have a more logical order to them. Which questions should be answered first, to narrow down options as quickly as possible? There might be a more perfect balance between questions that are easy to answer and questions that have the greatest effect on feasibility.

Accuracy of the Method

It is difficult to know how accurate the method findings are without field testing, but I do have some key observations.

The method does provide insight on the variables that affect the feasibility of each of the landscape-based methods on a site-by-site basis. It is key, however, that the practitioner applying this method knows the landscape and culture of the district well. Cultural questions such as aesthetic preferences and property rights concerns are taken into account by the method. These aspects will be different from place to place.

Complexities of the landscape are also not taken into account. I know from site visits that compost filter socks should have been ruled out for both of the diversion water sites. The constant, high flow rate of water from the Farmers Canal would translate to a shallow but expansive, permanent pool of water. These two sites are on rocky, well-drained, forested slopes, and Pine Creek is a fish bearing stream. The disruption to the hydrology and habitat of these areas that a landscape-based strategy would require would not be advisable, or probably legal. Clearly, the compost filter portion of the extent step needs to be re-worked to take this key element into account.

Utility of the Method

Farmers Irrigation District staff confirm that the findings from this exercise are of immediate use to them, and will be of interest to other irrigation districts dealing with the problems caused by suspended sediment.

VALIDATION: NEXT STEPS

Briefly, here are my recommended next steps for this project:

1. Gather feedback on the method framework from FID.
The decision making framework that I developed for this project is only the first stage in the method development process. Farmers Irrigation District of Hood River staff will review and critique the framework, and their feedback will inform revisions and future stages.

2. Expand the Method
The next stage in method development will be to expand the method to include all of the landscape-based strategies that remove sediment from water. This will require SWOT analyses of each of the strategies, and expansion of the method worksheets.

3. Use and critique the method
To test the revised method's transferability and usefulness, it will be employed and critiqued by FID and other irrigation districts.

4. Field test landscape-based strategies.
To test the accuracy of the method, landscape-based strategies that are deemed feasible through the method process will be field-tested by irrigation districts or in academic studies.

CURRENT SITE CONDITIONS

View facing southwest on Portland Drive

VEGETATED FILTER

View facing southwest on Portland Drive

COMPOST FILTER SOCKS

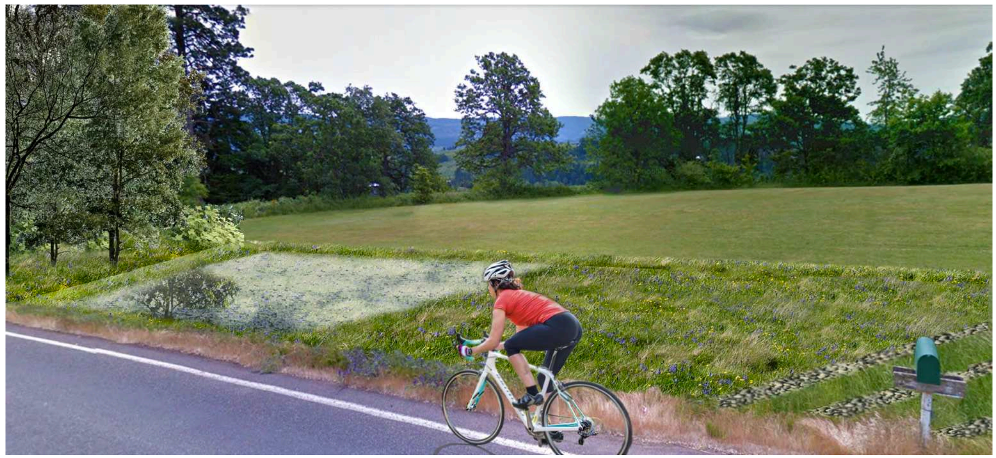
View facing southwest on Portland Drive

CURRENT SITE CONDITIONS

View facing southeast on Portland Drive

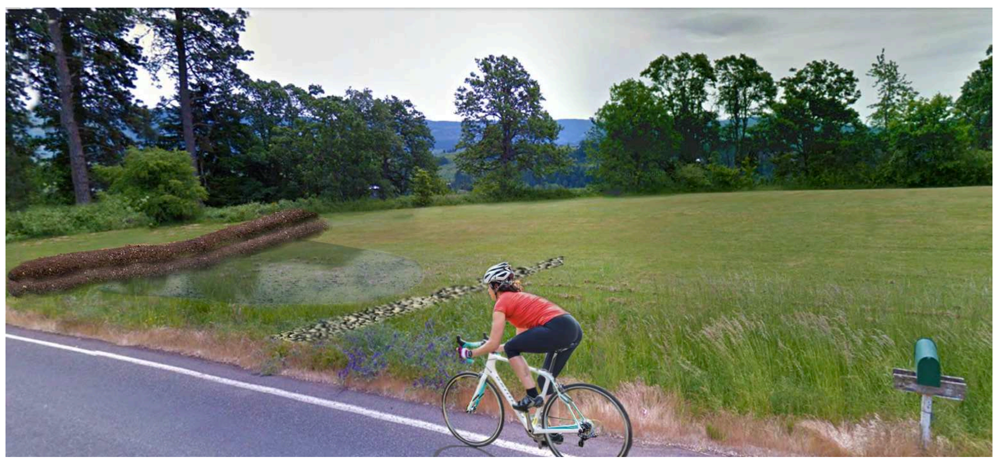
VEGETATED FILTER

View facing southeast on Portland Drive



COMPOST FILTER SOCKS

View facing southeast on Portland Drive



SOURCES CITED

Abu-Zreig, M. “Factors Affecting Sediment Trapping in Vegetated Filter Strips: Simulation Study Using Vfsmod.” Hydrological Processes. 15 (2001): 1477-1488. Print.

Archuelta, Ray. and Britt Faucette. *Agronomy Technical Note No. 4: Utilization of Compost Filter Socks.* United States Department of Agriculture, Natural Resources Conservation Service. 2011.

Borromeo Ferri, R. (2006b). *Modeling problems from a cognitive perspective.* In C. Haines et al. (Eds.), Mathematical Modeling (ICTMA 12): Education, Engineering and Economics (pp. 260–270). Chichester: Horwood.

Braskerud, BC. “Clay Particle Retention in Small Constructed Wetlands.” *Water Research*. 37.16 (2003): 3793-802. Print.

Cahill, M., D. C. Godwin, and M. Sowles. *Vegetated Filter Strips*. Oregon Sea Grant Fact Sheet. Product Number: ORESU-G-11-003. 2011.

Camp, C. R., et al. “SUBSURFACE DRIP IRRIGATION - PAST, PRESENT, AND FUTURE.” Proceedings of the 4th Decennial National Irrigation Symposium, Nov 14-16, 2000, Phoenix AZ.

Cappiella, K., et al. 2008. The Next Generation of Stormwater Wetlands. Center of Watershed Protection, Ellicott City, MD.

Clar, Michael L., Billy J. Barfield, and Thomas P. O’Connor. “Stormwater best management practice design guide volume 2 vegetative biofilters.” Document No. EPA/600/R-04 A 121 (2004).

Claytor, Richard A, and Thomas R. Schueler. *Design of Stormwater Filtering Systems*. Solomons, MD (P.O. Box 1280, Solomons 20688: Chesapeake Research Consortium, 1996. Print.

Edge, Douglas R. M, and Michael K. Dirks. “Problem Solving, Enrico Fermi and the Bull Moose.” School Science and Mathematics. 83.7 (1983): 601-608. Print.
Entrix. “WHI Environmental Foundation Study.” City of Portland. 15 (2001): 1477-1488. Print.

Environmental Protection Agency, National Pollutant Discharge Elimination System (NPDES) National Menu of Stormwater Best Management Practices. http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm, 2000.

Faucette, Britt, Frank Shields, and Kate Kurtz. “Removing stormwater pollutants and determining relations between hydraulic flow-through rates, pollutant removal efficiency, and physical characteristics of compost filter media.” 2nd Interagency Conference on Research in Watersheds Proceedings. 2006.

ESHA, Guide on How to Develop a Small Hydropower Plant. European Small Hydropower Association, 2003. Print.

Hatt, B.E, T.D Fletcher, and A Deletic. “Treatment Performance of Gravel Filter Media: Implications for Design and Application of Stormwater Infiltration Systems.” Water Research. 41.12 (2007): 2513-2524. Print.

Lamm, F. R., et al. “Subsurface drip irrigation: Status of the technology in 2010.” United States Department of Agriculture, 2012.

Pennsylvania Department of Environmental Protection (PA DEP). 2006. Pennsylvania Stormwater Best Management Practices Manual. PA DEP Report 363–0300-002. PA DEP: Harrisburg , PA.

Phillips, Michael J., et al. “Best management practices for riparian areas.” In: Riparian management in forests of the continental eastern United States. Lewis Publishers, Boca Raton, FL, 2000.

Ross, J., & Ross, M. *Fermi problems or how to make the most of what youalready know.* In Schoen, Harold L, and Marilyn Zweng. Estimation and Mental Computation: 1986 Yearbook. Reston, Va: National Council of Teachers of Mathematics, 1986. Print.

Rousseau, DP, PA Vanrolleghem, and Pauw N. De. “Model-based Design of Horizontal Subsurface Flow Constructed Treatment Wetlands: a Review.” *Water Research*. 38.6 (2004): 1484-93. Print.

Sample, David J. Best Management Practice Fact Sheet 13: Constructed Wetlands. Virginia Cooperative Extension (VCE) publication 426-132. http://pubs.ext.vt.edu/426/426-132/426-132.html. 2011.

Shock, C C. Drip Irrigation: An Introduction. Corvallis, Or.: Oregon State University, Extension Service, 2001. Print.

Swietlik, William, comp. *DEVELOPING WATER QUALITY CRITERIA FOR SUSPENDED AND BEDDED SEDIMENTS (SABS) Potential Approaches*. US EPA Office of Water Office of Science and Technology, 2003.

Von, Baeyer H. C. The Fermi Solution: Essays on Science. New York: Random House, 1993. Print.

APPENDICES

Appendix A. Farmers Irrigation District of Hood River

Mission Statement: Farmers Irrigation District strives to promote ecologically, socially, and economically sustainable agriculture by providing energy and irrigation service for the common good.

Source: http://www.fidhr.org

Structure and Funding: The Farmers Irrigation District (FID), founded by local farmers in 1874, is a non-profit quasi government agency that manages irrigation water in the Hood River Valley, located in Oregon's scenic Columbia River Gorge. FID provides water to over 1700 agricultural and residential end users over 5800 acres of land.

FID is governed by a five member board that meets monthly to set district water management policy. Each board member is elected by water rights holders to represent one of the five divisions that make up the district. FID also employs a district manager, who is responsible for district operations. During irrigation season (April 15 through September 30th), the district's primary role is to allot water to users and avoid disruptions to service. During off-season, they maximize flow to small, district-owned hydroelectric plants and work on maintenance projects.

Government and non-profit grants comprise FID's main source of funding. The district also collects usage and service fees from its end users and generates funds through the sale of surplus hydroelectric energy.

Source: http://www.fidhr.org

Past and Current Projects: FID diverts water directly from Hood River into the Farmer's Canal. It also draw water from the lower and upper Green Point Reservoirs (built in 1936 and 1937, respectively), and several creeks that are tributaries to Hood River and the Columbia River: Green Point Creek, Pine Creek, Ditch Creek, Indian Creek, and Phelps Creek.

As its mission statement implies, FID is dedicated to developing innovative projects to make its water distribution system efficient, cost effective and environmentally sustainable. Past and ongoing projects include: development of a self-clearing fish screen that safely guides fish out of irrigation diversions and back into the river; a sprinkler head exchange program wherein farmers and residential customers can trade in inefficient models for low-flow models; and two small-scale hydroelectric plants that run on canal water, built in 1985 and 1987.

Source:
http://www.fidhr.org/hydroelectric.htm

FID is currently in the process of updating its irrigation canals and pipes, many of which are over one hundred years old. The district is replacing this leaky infrastructure with high-volume PVC pipe, which allows for pressurized systems that conserve water and energy, makes water distribution more effective, and addresses water quality issues. In 2008 FID received a grant from Oregon's Department of Environmental quality for three million dollars to complete this ambitious project.

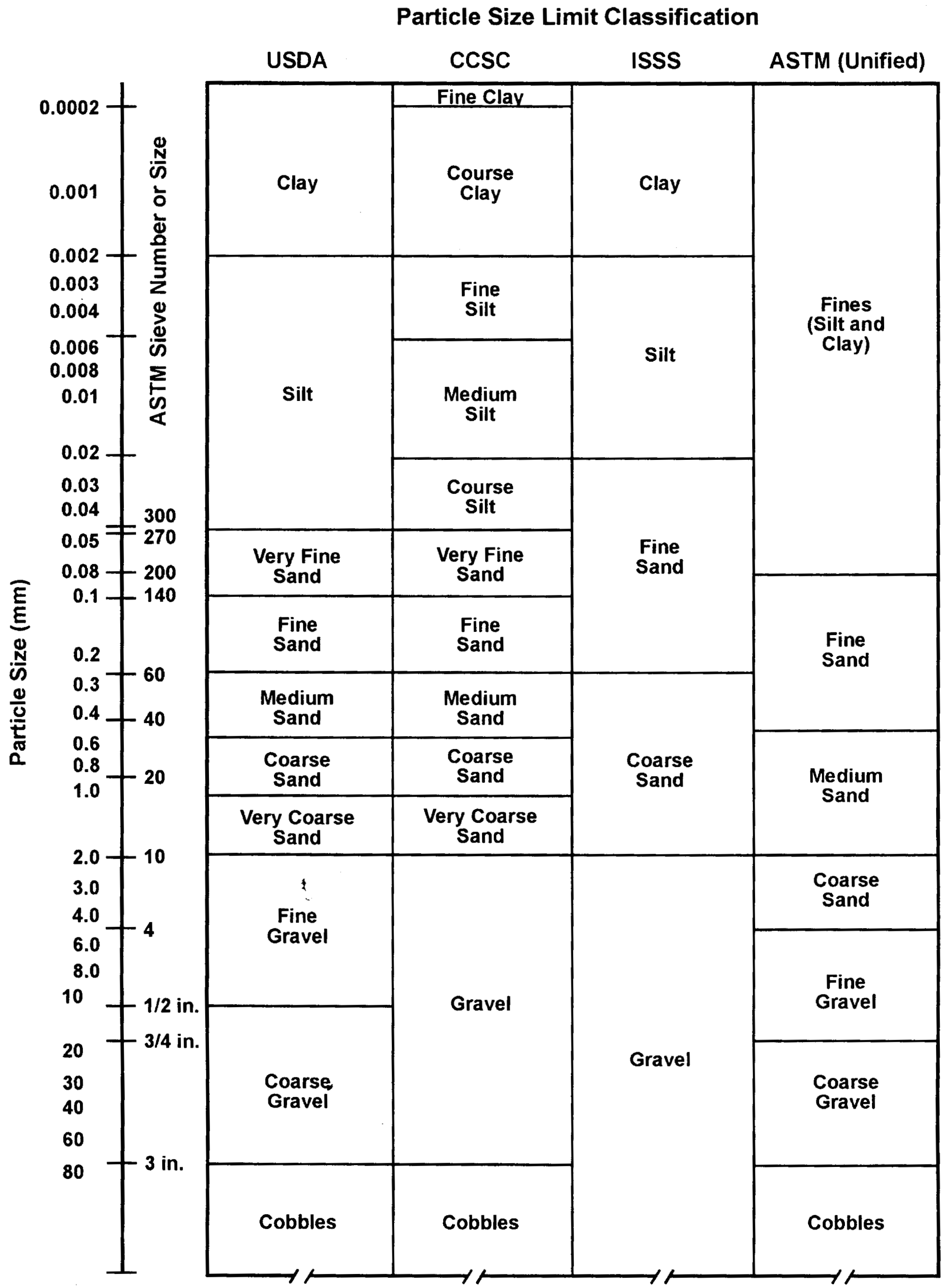
Source: (http://www.deq.state.or.us/news/prDisplay.asp?docID=2728)

Appendix B. Soil Classification Systems

B1. Particle Size Limit Classifications

- United States Department of Agriculture (USDA)
- Canada Soil Survey Committee (CCSC)
- International Soil Science Society (ISSS)
- American Society for Testing and Materials (ASTM)

Source: Gee, Glendon W., and Dani Or. "2.4 Particle-size analysis." Methods of soil analysis. Part 4 (2002): 255-293.



B2. Unified Soil Classification System

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES	FIELD INDENTIFICATION PROCEDURES (excluding particles larger than 3 inches and basing fractions on estimated weights)			INFORMATION REQUIRED FOR DESCRIBING SOILS
1	2		3	4	5			6
Coarse-grained Soils More than half of material is larger than No. 200 sieve size. (The No. 200 sieve size is about the smallest particle visible to the naked eye.)	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the ¼-in. size may be used as equivalent to the No. 4 sieve)	(Clean Gravels Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Wide range in grain sizes and substantial amounts of all intermediate particle sizes			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics. Give typical name: Indicate approximate percentage of sand and gravel, maximum size, angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information, and symbol in parentheses. Example: <u>Silty sand</u> gravelly; about 20% hard, angular gravel particles 1/2in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% non plastic fines with low dry strength; well compacted and moist in place; alluvial sand (SM).
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Predominatly one size or a range of sizes with some intermediate sizes missing			
		(Gravels with Fines Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures	Nonplastic fines or fines with low plasticity (for identification procedures see ML below)			
			GC	Clayey gravels, gravel-sand-clay mixtures	Plastic fines (for identification see CL below)			
	Sands More than half of coarse fraction is smaller than No. 4 sieve size	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines	Wide range in grain sizes and substantial amounts of all intermediate sizes missing			
			SP	Poorly graded sands or gravelly sands, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing			
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures	Nonplastic fines or fines with low plasticity (for identification			
			SC	Clayey sands, sand-clay mixtures	Plastic fines (for identification procedures see CL below)			
					Identification Procedures on Fraction smaller than No. 40 Sieve Size			
					Dry Strength (Crushing Characteristics)	*Dilatancy (Reaction to Shaking)*	*Toughness (Consistency near PL)*	
Fine-grained Soils More than half of material is smaller than No. 200 sieve size.	Silts and Clays Liquid limit is less than 50.		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. Give typical name, indicate degree and character or plasticity, amount and maximum size of coarse grains, color in wet conditions, odor (if any), local or geologic name, and other pertinent descriptive information, and symbol in parentheses. Example: <u>Clayey silt,</u> brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry and place; loess (ML).
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Medium to high	None to very slow	Medium	
			OL	Organic silts and organic silty clays of low plasticity	Slight to medium	Slow	Slight	
	Soils and Clays Liquid limit is greater than 50.		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Slight to medium	Slow to none	Slight to medium	
			CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High	
			OH	Organic clays and silts of medium to high plasticity	Medium to high	None to very slow	Slight to medium	
Highly Organic Soils			Pt	Peat and other highly organic soils	Readily identified by color, odor, spongy feel and frequently by fibrous texture			

Source: Western Michigan University Department of Geology http://www.wmich.edu/geology/

Appendix C. Estimating the Design Storm Volume
From: Design of Stormwater Filtering Systems (Claytor)

2.7 ESTIMATING WATER QUALITY VOLUME (WQV)

Two methods can be utilized to estimate the Water Quality Volume (WQV). Both rely on computing a volumetric runoff coefficient (R_v) and multiplying this by the rainfall volume to obtain a runoff volume in watershed inches.

The first method, or what we call the Short Cut Method, utilizes equation 2.1 to estimate the volumetric runoff coefficient R_v, (Schueler, 1987). It is recommended that the Short Cut Method be utilized where the site consists of predominately one type of land surface or for quick calculations to obtain a reasonably accurate estimate of treatment volume.

$R_v = 0.05 + 0.009(I)$ Equation 2.1

where I = site percent impervious

Therefore, the required treatment volume for a site will be equal to:

$WQV = P * R_v$ Equation 2.2

P = rainfall, in inches

and WQV = Water Quality Volume, in watershed inches

EXAMPLE CALCULATION

Assume a 3.0 acre shopping center which is 87% impervious, for a 1.0 inch rainfall event.

$R_v = 0.05 + 0.009(87\%)$

$R_v = 0.83$

for P = 1.0 inches

WQV = (1.0”)(.83) = .83 watershed inches

WQV = .83”(1/12 “/ft)(3.0 ac)(43,560 ft^2/ac) = 9,039 ft^3

The second method, or Small Storm Hydrology Method utilizes the work done by Pitt and others, to compute a volumetric runoff coefficient (Rv) based on the specific characteristics of the pervious and impervious surfaces of the drainage catchment. This method presents a relatively simple relationship between rainfall amount, land surface, and runoff volume. The Rvs used to compute the volume of runoff are identified in Table

2.13. The small storm hydrology model involves the following:

- For a given rainfall depth, the runoff coefficients for land surfaces present on the subject site are selected.
- A weighted runoff coefficient for the entire site is computed.
- If a portion of the site has disconnected impervious surfaces, reduction factors are applied to Rv. The reduction factors (from Table 2.14) are multiplied by the computed Rv for connected impervious areas to obtain the corrected value.
- For the given rainfall, the runoff volume (in watershed inches) is computed. WQV is equal to the rainfall times the Rv (same as equation 2.2 above).

TABLE 2.13: VOLUMETRIC COEFFICIENTS FOR URBAN RUNOFF (DIRECTLY CONNECTED IMPERVIOUS AREAS, ADAPTED FROM PITT, 1994)

Rainfall (inches)	Flat roofs and large unpaved parking lots	Pitched roofs and large impervious areas (large parking lots)	Small impervious areas and narrow streets	Sandy soils HSG-A	Silty soils HSG-B	Clayey soils HSG-C & D
0.75	.82	.97	.66	.02	.11	.20
1.00	.84	.97	.70	.02	.11	.21
1.25	.86	.98	.74	.03	.13	.22
1.50	.88	.99	.77	.05	.15	.24

TABLE 2.14: REDUCTION FACTORS TO VOLUMETRIC RUNOFF COEFFICIENTS FOR DISCONNECTED IMPERVIOUS SURFACES (ADAPTED FROM PITT, 1994)

Rainfall (inches)	Strip commercial and shopping center	Medium to high density residential with paved alleys	Medium to high density residential without alleys	Low density residential
0.75	.99	.27	.21	.20
1.00	.99	.38	.22	.21
1.25	.99	.48	.22	.22
1.50	.99	.59	.24	.24

In order to use the reduction factors for disconnected impervious surfaces, as general guidance, the impervious area above the pervious surface area should be less than one-half of the pervious surface and the flowpath through the pervious area should be at least twice the impervious surface flowpath.

The Small Storm Hydrology method has the advantage of evaluating the precise elements of a particular site and should be utilized for most design applications to estimate accurate runoff volumes. The method requires somewhat more effort to identify the specific land surface area ratios and additional effort is needed to assess the disconnections of impervious areas. The method rewards site designs which utilize disconnections of impervious surfaces by lowering the computed Rv and the required WQV.

EXAMPLE CALCULATION

Assume a 3.0 acre small shopping center having a 1.0 acre flat roof, 1.6 acres of parking and a 0.4 acre open space (sandy soil), for a 1.0 inch rainfall event and no disconnection of impervious surfaces. The weighted volumetric runoff coefficient is:

flat roof: 1.0 acre x .84 = 0.84

parking: 1.6 acres x .97 = 1.55

open space: 0.4 acre x .02 = 0.01

total: 3.0 acres = 2.40

weighted volumetric runoff coefficient Rv = 2.40/3.0 = .80
for P = 1.0 inches

Water Quality Volume (WQV) = (1.0”)(.80) = .80 watershed inches
= (.80”)((1 ft/12”)((3.0 ac)((43,560 ft2/ac)
= 8,712 ft^3

2.8 ESTIMATING PEAK DISCHARGE FOR THE WATER QUALITY STORM (Q_p)

The peak rate of discharge is needed for the sizing of off-line diversion structures and to design grass channels. As discussed earlier in this chapter, conventional

SCS methods underestimate the volume and rate of runoff for rainfall events less than 2”. This discrepancy in estimating runoff and discharge rates can lead to situations where a significant amount of runoff by-passes the filtering treatment practice due to an inadequately sized diversion structure or leads to the design of undersized grass channels.

The following procedure can be used to estimate peak discharges for small storm events. It relies on the volume of runoff computed using the Small Storm Hydrology Method and utilizes SCS, TR-55 Graphical Peak Discharge Method.

- Using the water quality volume (WQV), computed using the methods previously presented, a corresponding Curve Number (CN) is computed utilizing equation 2.3.

CN = 1000/[10 + 5P +10Q - 10(Q² + 1.25 QP)½]   Equation 2.3

where P = rainfall, in inches (use 1.0” for the Water Quality Storm)

and Q = runoff volume, in inches (equal to WQV)

Note: Equation 2.3 above, is derived from the SCS Runoff Curve Number method described in detail in NEH-4, Hydrology (SCS 1985) and SCS TR-55 Chapter 2: Estimating Runoff. The CN can also be obtained graphically (also from TR-55).

- Once a CN is computed, the time of concentration (tc) is computed (based on the methods identified in TR-55, Chapter 3: “Time of concentration and travel time”). The tc for small sites is often small based on relatively short flow paths; however, a minimum value of 0.1 hours should be used.
- Using the computed CN, tc and drainage area (A), in acres; the peak discharge (Q_p) for the Water Quality Storm is computed (based on the procedures identified in TR-55, Chapter 4: “Graphical Peak Discharge Method”). For the Chesapeake Bay Watershed use Rainfall distribution type II.
    - Read initial abstraction (I_a), compute I_a/P
    - Read the unit peak discharge (qu) from Exhibit 4-II for appropriate t_c
    - Using the water quality volume (WQV), compute the peak discharge (Q_p)

Q_p = qu(A(WQV   Equation 2.4

where Q_p = the peak discharge, in cfs
qu = the unit peak discharge, in cfs/mi²/inch
A = drainage area, in square miles
and WQV = Water Quality Volume, in watershed inches

EXAMPLE CALCULATION

Using the previous example:

where WQV = .80”

CN = 1000/[10+5(1.0”+10 *.80”-10((0.80”)²+1.25 * .80”(1.0”)½]

CN = 98

assume t_c = 10 minutes = .17 hours

Ia = 0.041 for CN = 98, I_a/P = 0.041/1.25” = .03

read q_u = 950 csm/in (TR-55 Exhibit 4-II)

A = 3.0 acres/640ac/mi² = .0047mi²

Q_p = 950 csm/in(.0047mi²(.80” =3.6 cfs

For computing runoff volume and peak rate for storms larger than the Water Quality Storm (i.e., 2, 10 and 100 year storms), use the published CN’s from TR-55 and follow the prescribed procedure in TR-55.

In some cases the Rational Formula may be used to compute peak discharges associated with the Water Quality Storm. The designer must have available reliable intensity, duration, frequency (IDF) tables or curves for the storm and region of interest. This information may not be available for many locations and therefore the TR-55 method described above is recommended.

Appendix D. Natural Drainage Classes

(As described in the Natural Resource Conservation Service's Soil Conservation Manual.)

Natural drainage class refers to the frequency and duration of wet periods under conditions similar to those under which the soil developed. Alteration of the water regime by man, either through drainage or irrigation, is not a consideration unless the alterations have significantly changed the morphology of the soil. The classes follow:

Excessively drained. Water is removed very rapidly. The occurrence of internal free water commonly is very rare or very deep. The soils are commonly coarse-textured and have very high hydraulic conductivity or are very shallow.

Somewhat excessively drained. Water is removed from the soil rapidly. Internal free water occurrence commonly is very rare or very deep. The soils are commonly coarse-textured and have high saturated hydraulic conductivity or are very shallow.

Well drained. Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. The soils are mainly free of the deep to redoximorphic features that are related to wetness.

Moderately well drained. Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent. The soils are wet for only a short time within the rooting depth during the growing season, but long enough that most mesophytic crops are affected. They commonly have a moderately low or lower saturated hydraulic conductivity in a layer within the upper 1 m, periodically receive high rainfall, or both.

Somewhat poorly drained. Water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. The occurrence of internal free water commonly is shallow to moderately deep and transitory to permanent. Wetness markedly restricts the growth of mesophytic crops, unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: low or very low saturated hydraulic conductivity, a high water table, additional water from seepage, or nearly continuous rainfall.

Poorly drained. Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season or remains wet for long periods. The occurrence of internal free water is shallow or very shallow and common or persistent. Free water is commonly at or near the surface long enough during the growing season so that most mesophytic crops cannot be grown, unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of low or very low saturated hydraulic conductivity of nearly continuous rainfall, or of a combination of these.

Very poorly drained. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. The occurrence of internal free water is very shallow and persistent or permanent. Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients may be greater.

Appendix E.

SUB-BASINS FOR FARMERS CANAL STORMWATER INPUTS

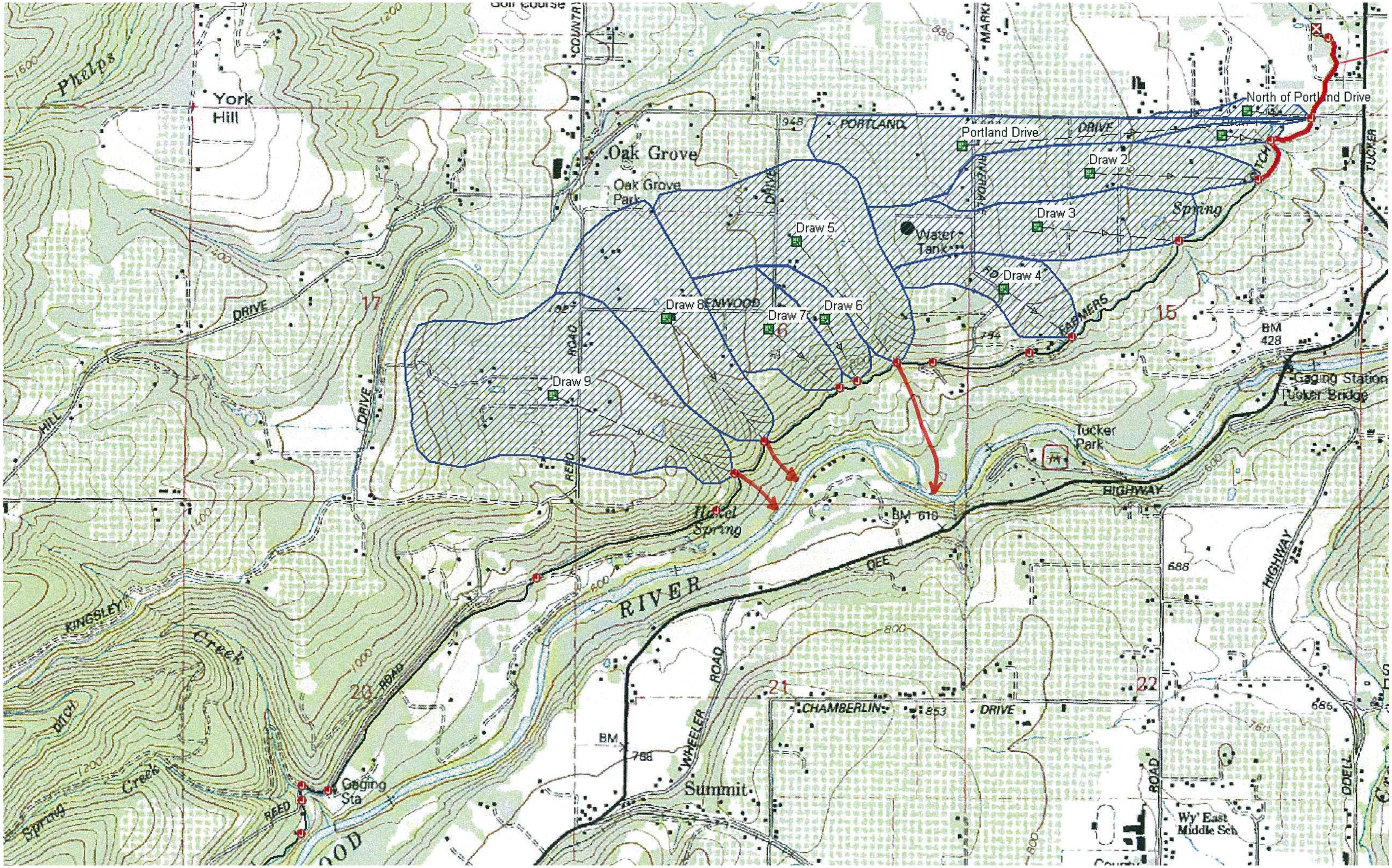


Figure 9. Map of Sub-basins for Farmers Canal Stormwater Inputs (Source: FID).

Appendix F.

ESTIMATED EXTENT RANGES

	Portland Rd	Draw 1	Draw 2	Draw 3	Draw 4	Draw 6	Draw 7	Pine Creek	Diversion
Flow rate (cfm)	91.2	11.4	67.8	64.2	42.6	22.2	52.2	4,380.00	4,380.00
Design Storm Volume (cf)	82743.31	10037.68	61227.57	58279.29	38766.59	20345.42	47363.88	n/a	n/a
30-day flow rate (cfm)	1.92	0.23	1.42	1.35	0.90	0.47	1.10	n/a	n/a
Veg min sf	608.00	76.00	452.00	428.00	284.00	148.00	348.00	29,200.00	29,200.00
Veg min acres	0.014	0.002	0.010	0.010	0.007	0.003	0.008	0.670	0.670
Veg max sf	9,120.00	1,140.00	6,780.00	6,420.00	4,260.00	2,220.00	5,220.00	438,000.00	438,000.00
Veg max acres	0.209	0.026	0.156	0.147	0.098	0.051	0.120	10.055	10.055
Compost min lf	22.80	2.85	16.95	16.05	10.65	5.55	13.05	1,095.00	1,095.00
Compost min miles	0.004	0.001	0.003	0.003	0.002	0.001	0.002	0.207	0.207
Compost max lf	60.80	7.60	45.20	42.80	28.40	14.80	34.80	2,920.00	2,920.00
Compost max miles	0.012	0.001	0.009	0.008	0.005	0.003	0.007	0.553	0.553
Wetland min sf	8,343.28	1,012.13	6,173.78	5,876.49	3,908.96	2,051.50	4,775.86	19,079,280.00	19,079,280.00
Wetland min acres	0.192	0.023	0.142	0.135	0.090	0.047	0.110	438.000	438.000
Wetland max sf	58,402.99	7,084.93	43,216.46	41,135.46	27,362.75	14,360.48	33,431.00	133,554,960.00	133,554,960.00
Wetland max acres	1.341	0.163	0.992	0.944	0.628	0.330	0.767	3,066.000	3,066.000
Subbasin area acres	73.53	8.92	54.41	51.79	34.45	18.08	42.09	n/a	n/a
Site area (or 5% of subbasin) acres	3.68	0.45	2.72	2.59	1.72	0.90	2.10	7.00	32.00
Longest Level Topo Line feet	644	645	1,230.00	1,177.00	1,028.00	408.00	602.00	1,104.00	3,052.00
Rule out	No rule out	No rule out	No rule out	No rule out	No rule out	No rule out	No rule out	W	W

Table 8. Estimate Extent Ranges for all FID sites.

Appendix G.

COST ESTIMATES FOR POTENTIALLY FEASIBLE LANDSCAPE-BASED STRATEGIES

	Portland Rd	Draw 1	Draw 2	Draw 3	Draw 4	Draw 6	Draw 7	Pine Creek	Diversion
Veg min extent acres	0.014								
Veg max extent acres	0.209								
Veg min build cost per acre	$ 13,000.00								
Veg max build cost per acre	$ 30,000.00								
Veg min maint cost per acre per year	$ 100.00								
Veg max maint cost per acre per year	$ 1,400.00								
Veg min build cost total	$ 181.45								
Veg max build cost total	$ 6,280.99								
Veg min maint cost total (10 years)	$ 13.96								
Veg max maint cost total (10 years)	$ 2,931.13								
Veg min cost total	$ 195.41								
Veg max cost total	$ 9,212.12								
Compost min extent lf	22.8	2.85	16.95	16.05	10.65	5.55	13.05	1095	1095
Compost max extent lf	60.8	7.6	45.2	42.8	28.4	14.8	34.8	2920	2920
Compost min build cost per linear foot	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00
Compost max build cost per linear foot	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00	$ 10.00
Compost min maint cost per linear foot per year	$ 0.20	$ 0.20	$ 0.20	$ 0.20	$ 0.20	$ 0.20	$ 0.20	$ 0.20	$ 0.20
Compost max maint cost per linear foot per year	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50	$ 0.50
Compost min build cost total	$ 68.40	$ 8.55	$ 50.85	$ 48.15	$ 31.95	$ 16.65	$ 39.15	$ 3,285.00	$ 3,285.00
Compost max build cost total	$ 608.00	$ 76.00	$ 452.00	$ 428.00	$ 284.00	$ 148.00	$ 348.00	$ 29,200.00	$ 29,200.00
Compost min maint cost total	$ 45.60	$ 5.70	$ 33.90	$ 32.10	$ 21.30	$ 11.10	$ 26.10	$ 2,190.00	$ 2,190.00
Compost max maint cost total	$ 304.00	$ 38.00	$ 226.00	$ 214.00	$ 142.00	$ 74.00	$ 174.00	$ 14,600.00	$ 14,600.00
Compost min cost total	$ 114.00	$ 14.25	$ 84.75	$ 80.25	$ 53.25	$ 27.75	$ 65.25	$ 5,475.00	$ 5,475.00
Compost max cost total	$ 722.00	$ 90.25	$ 536.75	$ 508.25	$ 337.25	$ 175.75	$ 413.25	$ 34,675.00	$ 34,675.00

Table 9. Cost Estimates for Potentially Feasible Landscape-Based Strategies