Utah State University
DigitalCommons@USU

All Graduate Plan B and other Reports | Graduate Studies

5-2011

Assessing Phosphorus-Transport from Biosolids Land Application Sites in Utah

Mohan K. Kumar
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/gradreports

Part of the Environmental Engineering Commons

Recommended Citation

Kumar, Mohan K., "Assessing Phosphorus-Transport from Biosolids Land Application Sites in Utah" (2011). *All Graduate Plan B and other Reports*. 85.
https://digitalcommons.usu.edu/gradreports/85

This Report is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Plan B and other Reports by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.

ASSESSING PHOSPHORUS-TRANSPORT FROM BIOSOLIDS LAND APPLICATION SITES IN UTAH

by

Mohan K Kumar

A report submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Environmental Engineering

Approved:

Michael McFarland Major Professor	David K. Stevens Committee Member
Dr. Gilberto E. Urroz Committee Member	

UTAH STATE UNIVERSITY
Logan, Utah

2011

Acknowledgments

I would like to express my sincere gratitude to my major professor, Dr. Michael McFarland for giving me the opportunity, support, and guidance to complete this work. For this I am truly grateful.

I would also like to thank the other members of my committee: Dr. David Stevens and Dr. Gilberto Urroz for their leadership and expertise.

Also, I would like to thank Leland Myers, the General Manager of Central Davis Sewer District, for his support.

Contents

Acknowledgments ... ii

List of Tables ... v

List of Figures ... vi

Abstract ... vii

Chapter 1 Introduction ... 1

Soil Phosphorus Transport and Eutrophication ... 1

Phosphorus in Soils ... 1

Land Application of Biosolids ... 2

Nutrient Management in Utah ... 3

Goals and Objectives ... 4

Chapter 2 Literature Review ... 5

Phosphorus in Biosolids ... 5

Stabilization of Biosolids ... 5

Phosphorus Site Index ... 7

Interpretation of PSI Value Ratings ... 8

Phosphorus Transport Modeling: CropMAN (EPIC model) ... 9

EPIC model ... 10

EPIC Description ... 10

Chapter 3 Study Sites ... 12

Study Sites ... 12

Skull Valley, Utah Biosolids Land Application Site ... 13

Central Davis, Utah Biosolids Land Application Site ... 15

Description of parameters used for PSI calculations ... 17

Statistical Analysis ... 19

Chapter 4 EPIC Simulations ... 20

Inputs and Outputs of Model ... 20

Soil Data ... 20

Weather 20
Fertilizer 21
Management and Cropping Systems 21
Chapter 5 Phosphorus Site Index 27
PSI Components 27
Soil Erosion 27
Irrigation Erosion 28
Runoff Class 29
Soil Phosphorus Concentration 29
Phosphorus Fertilizer Application Rate and Method 30
PSI Calculations 30
PSI Weighting Factors model fit 32
Chapter 6 Conclusions and Engineering Significance 34
Best Management Practices 34
Chapter 7 Conclusions 35
Utah PSI Calculator Worksheet 36
References 37
Appendices 42
Appendix A Skull Valley PSI Calculations 43
Appendix B Central Davis Site PSI Calculations 46
Appendix C Soil Erosion Estimation, Utah 48
Appendix D CropMAN Input 50
Appendix E CropMAN Output 55
Appendix F Skull Valley Site PSI Calculations using NRCS guidelines 56
Appendix G Central Davis Site PSI Calculations using NRCS guidelines 60

List of Tables

1 Utah-NRCS P Management Limits 3
2 PSI using NRCS Guidelines 8
3 P Assessment, NRCS (1994) 8
4 Application rates of biosolids at Skull Valley Site 13
5 Percent nitrogen in biosolids 14
6 phosphorus mass balance in skull Valley study site 14
7 soil P test, Skull Valley site 15
8 EPIC simulations for application year 21
9 Soil erosion calculation for Central Davis site 27
10 Soil erosion calculation for Skull Valley site 28
11 Phosphorus Site Indices 31
12 Interpration table for UT-PSI 31
13 Weighting factors 32
14 Utah PSI Interpretation 32

List of Figures

15 Phosphorus Cycle.. 2
16 Biosolids land application in Skull Valley, Utah.. 6
17 Biosolids land application site location along with weather station location................ 12
18 Aerial photograph of Skull Valley biosolids land application site with soil map units. 12
19 Skull Valley Biosolids land application site zones.. 13
20 Aerial photograph of CDSD biosolids land application site with soil map units.......... 16
21 Soil test P, CDSD Site.. 17
22 Total soil phosphorus in study sites.. 22
23 phosphorus losses in study sites.. 23
24 mineralized phosphorus in study sites.. 24
25 phosphorus loss from sites vs. phosphorus site indices.. 24
26 phosphorus loss from sites vs. bisolids application rates.. 25
27 phosphorus loss from sites vs. soil test P values.. 25
28 soil test P vs. biosolids application rates.. 30
29 Utah-PSI worksheet.. 36

Abstract

Phosphorus Site Index (PSI) is a phosphorus transport assessment tool used to estimate the risk of P transport from soils. Various components, such as soil erosion, P fertilizer application rate, plant available P in soil, etc. that have an influence on P transport from a site, are weighted and given ratings, and a combination of these components are expressed as PSI. This study has considered two biosolids land application sites in Utah, which received biosolids amendments over time, to develop a specialized PSI for the state of Utah.

Phosphorus from land application of biosolids has been considered a potential risk to eutrophication. While EPA Part 503 Title 40 Code of Federal Regulation (CFR) regulations mandate certain application practices, a more accurate tool is necessary to estimate P losses from biosolids land application sites.

The PSI for the two biosolids land application sites in Utah was calculated and the validity of their weighting factors and loss ratings were established. Erosion-Productivity Impact Calculator (EPIC) model was used to simulate P transport over these sites to further determine the accuracy of PSI. While application of the P-Index is not currently a regulatory requirement in Utah, increasing public and regulatory concerns have led to development of P-Index charts in various states, which can be used to estimate the potential risk of phosphorus mobility and environmental impact. Based on the validated PSI model, a PSI worksheet was developed in an easy to use form, covering recommended best management practices and methods of preventing P transport from soils, based on ranking of the PSI values.

Chapter 1 Introduction

Soil Phosphorus Transport and Eutrophication

Phosphorus in biosolids is present both in dissolved and particulate forms. However, when land applied to mineral soils, most dissolved phosphorus rapidly combines with metal species (primarily aluminum, calcium or iron) to form particulate phosphorus salts. Percentages of particulate and dissolved phosphorus in soils vary with soil characteristics. Dissolved orthophosphates (HPO_4^{2-} and $H_2PO_4^{2-}$) are the most common forms of soluble phosphorus in soils. Based on the magnitude of its solubility product constant (K_{sp}), calcium phosphate is the most soluble form of phosphorus found in soil (Vu Tran, 2008). Active soils P are the form of phosphates that are easily dissolved into the water in the soils, governed by the concentrations of dissolved P in the soils. Thus active P is considered the main source of phosphorus for crops (Lowell Busman, 2009).

The concentration of phosphorus in agricultural soils varies from 50 to 1500 mg/kg with up to 70% of the total phosphorus found in inorganic particulate form (Pierzynski, 2000; Vu Tran, 2008). Total phosphorus in biosolids typically varies from 10 to 20 gm/kg (Peters, 1996).

Phosphorus transport from soils has represented a major source of phosphorus pollution in Utah surface soils, resulting in eutrophication. Eutrophication is considered a major source of water pollution (Vu Tran, 2008). The NRCS P Management limits (Table 1) have attempted to include non-point sources of phosphorus for best management practices. Limits of biosolids application rates have also been developed based on soil phosphorus levels to check over application of biosolids. While many states have developed the phosphorus site index, a comprehensive phosphorus tracking tool, others regulate phosphorus fertilizer application rates based on agronomic rates calculated from plant nitrogen or phosphorus requirements (Cardon, Kotuby-Amachar, hole, & Koenig, 2008).

Phosphorus in Soils

Iron, aluminum and calcium phosphates are the three main groups of phosphorus fixing elements in soils (Maguire, Sims, & Coale, 2000). Many sequential and non- sequential extraction methods have been developed to obtain the phosphorus fractions to quantify the various groups of phosphates (Zhang & Kovar, June 2009). Concentrations of these phosphates play a major role in the concentrations of plant available phosphorus as well as the phosphate distribution behavior in soils added with Al or Fe containing biosolids. While types of soils (acidic, neutral or alkaline) play a major role in the amounts phosphorus fractions formed (Maguire, Sims, & Coale, 2000), it is important to understand the effect of addition of different types of biosolids (addition of metal salts, lime, biologically treated etc.) to soils and the resulting risks involved in

P transport. Plant available or environmentally available P is currently considered accurate measurements of risk of P losses from soils (Sims R. M., 2001)

The concentration of phosphorus in agricultural soils varies from 50 to 1500 mg/kg with up to 70% of the total phosphorus found in inorganic particulate form (Pierzynski, 2000) (VuTran, 2008). Total phosphorus in biosolids typically varies from 10 to 20 gm/kg (Peters, 1996).

Land Application of Biosolids

Sixty percent of biosolids produced in the United States are land applied. Recycling of biosolids for agricultural use makes use of the plant required nutrients while also preventing storage and disposal of biosolids. Understanding the effects of oversaturation of phosphorus through biosolids addition is necessary to prevent transport of phosphorus from soils and to preserve soils for future agricultural use (Kinney, et al., 2006). It is known that the concentrations of different phosphorus fractions in soils, and the addition of biosolids with will not adversely affect the risk of P transport from soils (Maguire, Sims, & Coale, 2000). Remedial measures will attempt to both prevent over application of phosphorus, as well as suggest methods of removal of phosphates to reduce the risk through selective cropping and other farming practices.

Under most circumstances, the concentration of phosphorus in biosolids is relatively high when compared to plant available nitrogen in biosolids. This means that establishing biosolids land application rates based on nitrogen requirements of crops will inherently result in an over application of phosphorus. If not managed properly, the accumulation of phosphorus on agricultural sites including those that receive biosolids could increase the risk of eutrophication in nearby surface waters (Figure 1).

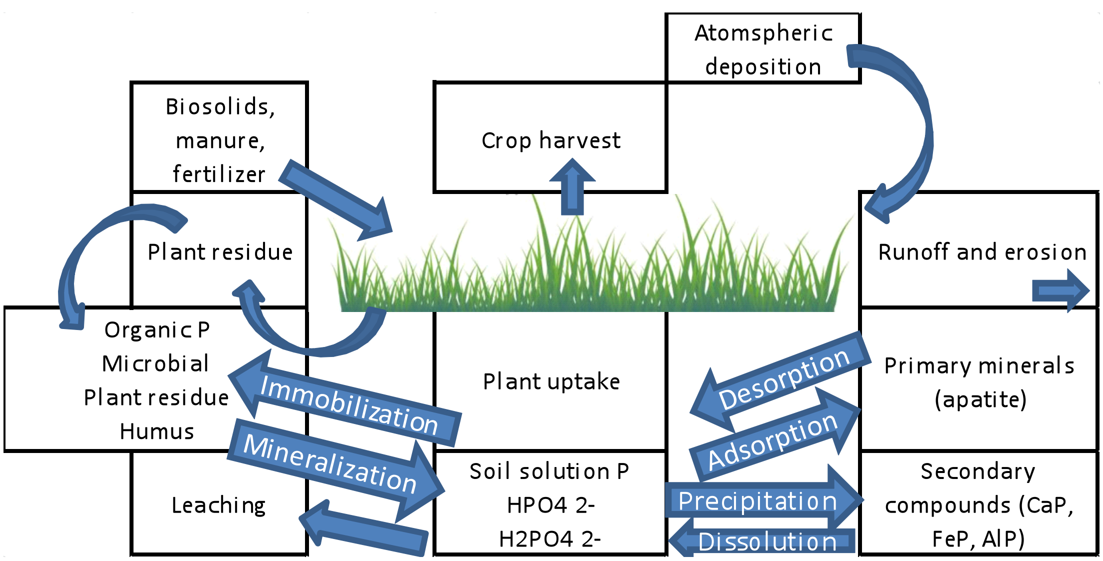


Figure 1 Phosphorus Cycle

Currently, the state of Utah does not require monitoring of biosolids phosphorus loading on or from land application activities. The application rate of biosolids is limited primarily by nitrogen considerations although both national and Utah state rules require that biosolids land application not adversely impact surface water quality. The National Resource Conservation Service (NRCS) sets guidelines for P management for each state. The 590 NRCS Nutrient Management Standard has also set limiting numbers for organic/inorganic phosphorus fertilizers based on the risk of P transport from soils, as shown in Table 1. To date, it is unknown, to what extent P transport from biosolids land application sites poses a concern in the protection of surface water quality within the state of Utah. To address this issue, this study focused on applying the NRCS based PSI approach to well-defined biosolids land application sites within the state of Utah to identify the P transport parameters and their appropriate weighting factors that reasonably characterize the risk of phosphorus mobility from such activities.

Table 1 Utah-NRCS P Management Limits (NRCS, 1994)

Soil test phosphorus (STP), ppm*	**Apply biosolids based on -**
less than 50	agronomic rate for nitrogen
50 to 100	crop phosphorus removal rate
greater than 100	application not recommended

Nutrient Management in Utah

Utah Manure Application Rate Index (UMARI) and Utah Animal Feedlot Runoff Risk Index (UAFRRI) are two nutrient management tools developed for the state of Utah . Both tools are designed to account for the transport factors of nutrients. They do not account for the source and site management terms of soil nutrients, including organic and inorganic fertilizer application methods and rates.

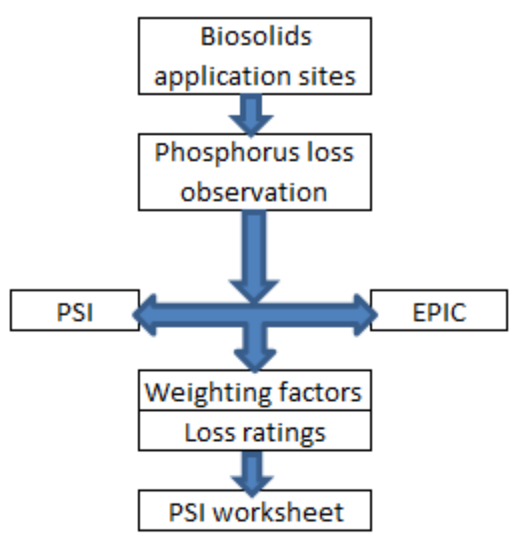
Though phosphorus is limited by the NRCS 590 guidelines in terms of application rates, a single comprehensive method or tool is currently unavailable for the state of Utah to track soil phosphorus. Soil P tests are also not considered as a P transport factor either by UMARI or UAFRRI.

Goals and Objectives

The overall goal of this study is to evaluate the risk of P-transport associated with biosolids land application practices in the state of Utah. To achieve this goal, the following research objectives were pursued.

- Using the standard phosphorus site index (PSI), evaluate the transport of phosphorus from biosolids land application sites in Davis and Tooele counties. The PSI uses the guidelines set by NRCS (NRCS, 1994)
- Apply EPIC model to provide an estimate of soluble and particulate P loss from the Davis and Tooele county biosolids land application sites.
- Based on comparing the results from the PSI and EPIC model simulations, develop refined weighting factors that can be utilized to develop a Utah specific PSI model for biosolids managers.
- Develop an easy to use PSI worksheet for the state of Utah based on the PSI formulation with soils and weather databases.

Methodology Flow Diagram



Chapter 2 Literature Review

In compliance with the requirements of Section 405 (d) of the 1987 Clean Water Act amendments, on February 19, 1993, the final version of 40 Code of Federal Regulations (40 CFR) Part 503 - "Standards for the Use or Disposal of Biosolids" was published in the Federal Register. In the 40 CFR Part 503 rule, the term "biosolids" was introduced as a replacement for the term municipal sewage sludge. The new term was designed to reflect the beneficial characteristics of the residual solids from municipal wastewater treatment processes. The new legislation (40 CFR Part 503) defines biosolids as the final solid, semi-solid or liquid residue generated during the treatment of domestic sewage in a municipal wastewater treatment plant (McFarland, 2001).

Phosphorus in Biosolids

Stabilization of Biosolids

Stabilization of biosolids is done in sludge treatment to either reduce or eliminate vector attraction potential, or to reduce pathogen concentrations, apart from elimination of offensive odors (McFarland, 2001). The five most commonly used methods to stabilize biosolids are:

a) Anaerobic digestion
b) Aerobic digestion
c) Lime treatment
d) Chlorine oxidation and
e) Composting

Under most circumstances, the concentration of phosphorus in biosolids is relatively high when compared to plant available nitrogen in biosolids. This means that establishing biosolids land application rates based on nitrogen requirements of crops will inherently result in an over application of phosphorus. If not managed properly, the accumulation of phosphorus on agricultural sites including those that receive biosolids could increase the risk of eutrophication in nearby surface waters (Figure 1).

Phosphorus in biosolids is present both in dissolved and particulate forms. However, when land applied to mineral soils, most dissolved phosphorus rapidly combines with metal species (primarily aluminum, calcium or iron) to form particulate phosphorus salts. Percentages of particulate and dissolved phosphorus in soils vary with soil characteristics. Dissolved orthophosphates (H_2PO^{-4} and HPO_4^{-2}) are the most common forms of soluble phosphorus in soils. Based on the magnitude of its solubility product constant (K_{sp}), calcium phosphate is the most soluble form of phosphorus found in soil (Vu Tran, 2008). Active soils P are the form of phosphates that are easily dissolved into the water in the soils, governed by the concentrations of dissolved P in the soils. Thus active P is considered the main source of phosphorus for crops (Busman et al. 2009).

Land application of biosolids includes all forms of applying bulk or bagged biosolids to land for beneficial use (Figure 1 Phosphorus Cycle). These beneficial uses include biosolids application to: 1) agricultural land for food production, 2) agricultural land for production of feed and fiber crops, 3) pasture and range land, 4) non-agricultural land (*e.g.*, forests), 5) disturbed lands (*e.g.*, highway embankments, mine reclamation, *etc*.), 6) construction sites and gravel pits, 7) public contact sites (*e.g.,* parks and golf courses), and 8) home lawns and gardens.

Approximately sixty percent of all biosolids generated in the US are recycled through land application (Kinney, et al., 2006). Although biosolids land application rates are typically limited by nitrogen considerations, concern over the fate of phosphorus from agricultural operations and its role in increased frequency of eutrophication have raised regulatory and public concern over the transport of phosphorus from biosolids beneficial use activities. Sustainability of land application of biosolids has also been of concern where phosphorus based agronomic rate calculations are mandated. A typical application requires approximately three times more land area for application of biosolids when the application rate is calculated based on phosphorus as compared to nitrogen.

A recent survey found at least 24 states to have existing regulations that limit biosolids application rates based on phosphorus levels in the soil (Sims A. L., 2002). A high level of phosphorus in soil increases the risk of phosphorus transport from the site to surface water through wind and/or water erosion of topsoil. Once phosphorus reaches surface waters, it is often the limiting nutrient for the production of undesirable aquatic plant species (i.e., eutrophication).

Over the past six years, Utah State University has been investigating the environmental impact of land applying large amounts of biosolids for restoring marginal and/or disturbed rangelands. A number of biosolids field test sites have been established in Skull Valley, Utah, which is located in Tooele County, Utah approximately 30 miles west of Salt Lake City, UT (Figure 2).

Figure 2 Biosolids land application in Skull Valley, Utah

The impact of large biosolids application on rangeland forage quality and quantity was evaluated. Aerobically digested, anaerobically digested and lime-stabilized biosolids were used throughout the field tests (Vasquez, 2008). Soil phosphorus concentrations were taken at various depths as well as biosolids loading rates at these sites. This data set will be used to develop the appropriate weighting factors for designing a Utah-based PSI management tool. Once the tool is developed, it will be validated using phosphorus data sets obtained from the Central Davis Sewer District and other sewer agencies within the state of Utah.

Phosphorus Site Index

The Phosphorus Site Index (PSI) is a model that can be used to evaluate the potential phosphorus transport from biosolids land application sites. The results of a PSI evaluation, which depends on both site characteristics and management practices, provide land managers with a method to evaluate their fields and to make scientifically defensible management decisions. The PSI takes into consideration a number of site-specific factors, including land slope, runoff potential, proximity to surface water, soil phosphorus levels and phosphorus application rates. When the parameters of the PSI are analyzed, the primary factors that limit phosphorus movement can be identified. These factors (or parameters) can be the basis for planning corrective soil and water conservation practices and management techniques.

The main factors accounted for in the calculation of PSI are soil erosion, irrigation erosion, runoff class, soil phosphorus concentration, phosphorus application rates and methods of application (NRCS, 1994) and proximity to water. The sum of all the values, each of which is multiplied by a weighting factor, is reported as a PSI level which is further categorized based on the risk potential as low, medium, high or very high Table 2.

The factors are as listed:

1. soil erosion (SE)
2. irrigation erosion (IE)
3. runoff class (RC)
4. soil phosphorus concentration (Ptest)
5. phosphorus fertilizer application rate (IPrate)
6. phosphorus fertilizer application method (IPmethod)
7. organic phosphorus source application rate (OPrate)
8. organic phosphorus source application method (OPmethod)

PSI is calculated as:

PSI=SE LR*(1.5) + IE LR*(1.5) + RC LR*(0.5) + Ptest LR*(1) + IPrate LR*(.75) + IPmethod LR*(.5) + OPrate LR*(1) + OPmethod LR*(1)

Where LR is the loss rating for the component, values obtained from Table 2.

Table 2 PSI using NRCS Guidelines

SITE CHARACTERISTIC (weighting factor)	**PHOSPHORUS LOSS RATING (VALUE)**				
	NONE (0)	**LOW (1)**	**MEDIUM (2)**	**HIGH (4)**	**VERY HIGH (8)**
SOIL EROSION (1.5)	NOT APPLICABLE	<5 TONS/AC	5-10 TONS/AC	10-15 TONS/AC	>15 TONS/AC
IRRIGATION EROSION (1.5)	NOT APPLICABLE	TAILWATER RECOVERY or QS<6 for very erodible soils or QS*<10 for other soils	QS>10 for erosion resistant soils	QS>10 for erodible soils	QS>6 for very erodible soils
RUNOFF CLASS (0.5)	NEGLIGIBLE	VERY LOW or LOW	MEDIUM	HIGH	VERY HIGH
SOIL P-TEST (1.0)	NOT APPLICABLE	LOW	MEDIUM	HIGH	EXCESSIVE
P-FERTILIZER APPLICATION RATE (0.75)	NONE APPLIED	1-30 P_2O_5 LBS/AC	31-90 P_2O_5 LBS/AC	91-150 P_2O_5 LBS/AC	> 150 P_2O_5 LBS/AC
P-FERTILIZER APPLICATION METHOD (0.5)	NONE APPLIED	PLACED WITH PLANTER DEEPER THAN 2 INCHES	INCORPORATED IMMEDIATELY BEFORE CROP	INCORPORATED > 3 MONTHS BEFORE CROP or SURFACE APPLIED < 3 MONTHS BEFORE CROP	SURFACE APPLIED > 3 MONTHS BEFORE CROP
ORGANIC P SOURCE APPLICATION RATE (1.0)	NONE APPLIED	1-30 P_2O_5 LBS/AC	31-60 P_2O_5 LBS/AC	61-90 P_2O_5 LBS/AC	> 90 P_2O_5 LBS/AC
ORGANIC P SOURCE APPLICATION METHOD (1.0)	NONE	INJECTED DEEPER THAN 2 INCHES	INCORPORATED IMMEDIATELY BEFORE CROP	INCORPORATED > 3 MONTHS BEFORE CROP or SURFACE APPLIED < 3 MONTHS BEFORE CROP	SURFACE APPLIED TO PASTURE, or > 3 MONTHS BEFORE CROP

*QS – product of flow rate of water in furrow and furrow slope, flow rate in gpm and slope in %

Interpretation of PSI Value Ratings

The following site PSI value categories have been established by the NRCS as a general guideline Table 3. These categories reflect the relative susceptibility of the site to phosphorus transport based on the factors previously described.

Table 3 P Assessment, NRCS (1994)

Total of Weighted Rating Values	Site Vulnerability
< 8	LOW
8 -14	MEDIUM
15 - 32	HIGH
> 32	VERY HIGH

1. Low site vulnerability suggests no adverse impact of biosolids application on surface water quality

2. Medium site vulnerability indicates that some remedial actions to reduce the probability of phosphorus movement are warranted.
3. High site vulnerability indicates an unacceptable risk that phosphorus transport will have a negative impact on surface water quality. Implementing soil and water conservation practices are strongly recommended to lower the probability of significant phosphorus movement.
4. Very High site vulnerability indicates a high probability of phosphorus transport to surface waters. Remedial actions will include both water and soil conservation and phosphorus management plans to reduce water quality degradation.

The PSI ratings of low, medium, high, or very high determines the extent to which land managers and/or biosolids appliers must adopt best management practices (BMPs) to reduce the potential of phosphorus transport from the site. Soil incorporation of biosolids through tilling or injection as well as establishing vegetated buffers are examples of BMPs that may reduce the PSI rating. Other BMP examples include subdividing an existing field into smaller phosphorus management units. For example, if there were a highly sloped section of a biosolids land application site, it could be could be terraced so that it maintained a permanent vegetative cover.

It should be noted that, in characterizing the risk of eutrophication from P transport associated with biosolids land application sites, the PSI value does not take into account the actual distance between the surface water body and the biosolids land application site boundary. PSI only characterizes the likelihood that site conditions will result in a significant movement of phosphorus from the site.

If the distance between the surface water body and the biosolids beneficial site boundary is relatively short (i.e., 10 to 1000 meters), the impact of a high or very high PSI rating on surface water quality impairment should be a concern to biosolids decision-makers. On the other hand, if the distance between the surface water body and the biosolids beneficial site boundary is relatively long (i.e., > 10 kilometers), the impact of P movement from the biosolids land application site on surface water quality is probably minor regardless of the PSI rating. In all cases, professional judgment must be employed in determining whether the distance between the biosolids land application site boundary and the surface water is a mitigating factor in characterizing the potential impact of P movement on water quality protection.

Phosphorus Transport Modeling: CropMAN (EPIC model)

The Environmental Policy-integrated Climate computer simulation model was developed by the USDA. The model uses a daily time step simulation to account for changes in resources. EPIC was primarily developed as a field scale simulator; it considers a drainage area of 20 acres (BREC, August 2006).

For Skull Valley, UT biosolids land application sites applying aerobically digested, anaerobically digested and lime stabilized biosolids, the Utah derived PSI model predictions was compared with the predictions of the established phosphorus tracking tool EPIC.

The mathematical model EPIC was designed to relate soil erosion and soil productivity for the U.S.A. EPIC has been used to model drainage, irrigation, wind and water erosion, fertilizer application rates etc. among various other site and management characteristics. The nine major components of EPIC are: hydrology, weather, erosion, nutrients, soil temperature, plant growth, tillage, plant environment control and economics (Williams J. R., 1990). EPIC was incorporated in the Soil and Water Resources Conservation Act in 1985, and has since been validated for numerous land areas in the U.S.A.

EPIC was developed with a goal of accurate field-scale modeling. Numerous nutrient cycling and loss validation studies have been done using EPIC. While inaccuracies were reported in modeling soluble P, correct predictions for total P in subwatersheds was obtained with EPIC modeling (Forster et al 2000). Also long term trends were more accurate while modeling phosphorus as compared with single events (Chung et al 1999). These issues were considered when modeling for phosphorus from the biosolids land application sites.

EPIC model

This section describes the validation of PSI estimates using simulated data from Crop Management Simulated (CropMAN) model. Environmental Policy-Integrated Climate model (EPIC) serves as the platform for CropMAN. EPIC is based on a continuous daily time step modeling platform with the capability to model several crops along several years. As EPIC modeling platform simulations are generally performed on a field sized area of 250 acres which are assumed to be homogenous sites. In other words weather, soil, and management systems are assumed to be homogenous thus serving well for this modeling effort. Major components of EPIC which are of interest to this study are weather, hydrology, erosion-sedimentation, nutrient cycling, plant growth, soil temperature, tillage, and plant environmental control (Gerik, 2006).

EPIC which was formerly known as Erosion Productivity Impact Calculator (EPIC) was developed for simulating the effects of soil erosion on crop productivity by the USDA-(Agriculture Research Service) ARS which was later expanded to include the soil Phosphorus model (Jones, 1984; Gerik, 2006).

EPIC has successfully predicted P transport for various agricultural settings in the US. Examples of such modeling efforts include work done by (Wang, 2006; Mullins, 1997), and (Edwards, 1993) for P modeling under manure application conditions and agricultural settings such as a pasture (Mullins, 1997; Wang, 2006; Edwards, 1993). EPIC was also used to simulate the impact of poultry litter application in Alabama on P movement from pastures (Torbert, 2008).

EPIC Description

The components of EPIC relevant to this study are briefly described in the following paragraphs. The hydrology component consists of surface runoff, percolation, lateral subsurface flow, evapotranspiration, and snow melt. Runoff is predicted using the modified Soil

Conservation Service (SCS) curve number method. A storage routing technique is used to predict flow through each soil layer in the root zone. The saturated hydraulic conductivity of the soil layer determines the downward flow rate with no percolation occurring below $0^{o}C$. Land slope and saturated conductivity dictates the later subsurface flow. CropMAN interface offered two options to determine evapotranspiration, namely; Penman-Monteith and Hargreaves methods. On those when the maximum temperature exceeds $0^{o}C$, the model considers the snow to have melted (Williams J. R., 1990),

The weather component further can be divided into precipitation, air temperature and solar radiation, wind, and relative humidity (Williams 1990). The required model input for precipitation model of EPIC is total daily precipitation values for the time period being considered for the simulation. Using the average daily air temperature the model simulates the presence of a rainfall or a snowfall event (BREC 2003). When only maximum and minimum daily temperature is provided as input the model has options to simulate other weather variables such as solar radiation and/or relative humidity. Average daily wind velocity and wind direction are used to determine the wind erosion component. Wind and water erosion are computed by EPIC. Three generators of water erosion being considered by EPIC are rainfall, runoff, and irrigation. Soil texture, organic content, and crop management factor are used to estimate the soil erodibility factor need for modeling soil erosion. The coarse fragment content is then used to adjust the erosion estimates. Daily wind erosion predictions are computed by EPIC. (Williams 1990)

Nitrogen and phosphorus movement can both be modeled using EPIC. This study only looked at the P component of the EPIC model. A partitioning factor, labile P concentration along with the calculated runoff estimates are used to model the soluble P concentration in runoff. Primarily P is associated with the sediment phase. The sediment transport of P is simulated using the loading function which estimates the daily organic P runoff based on the organic P on the top soil layer, sediment yield, and enrichment ratio. The concentration of P and the P sorption coefficient determines the flow between the active and stable mineral P pools. Soil water, temperature, labile P concentration, organic P weight is all used to estimate the mineralization fraction from the organic P pool. (Williams J. R., 1990).

EPIC platform allows for simulation of both dry land based farming operation and a irrigated farming operation. Although the model is capable of simulating up to 10 soil layers, data was only available for 5 layers. Built-in datasets of EPIC for the state of Texas consist of data for about 8000 weather locations, 50 types of farm equipment, and 737 soils to aid in the ease of use of the model. (Williams J. R., 1990).

Chapter 3 Study Sites

Study Sites

Two sites that received biosolids amendments, Ensign Ranch, Skull Valley, UT and Central Davis WWTP agriculture property by Farmington bay, were used to calculate the phosphorus site indices Figure 3. Different types of biosolids with different phosphorus levels were applied.

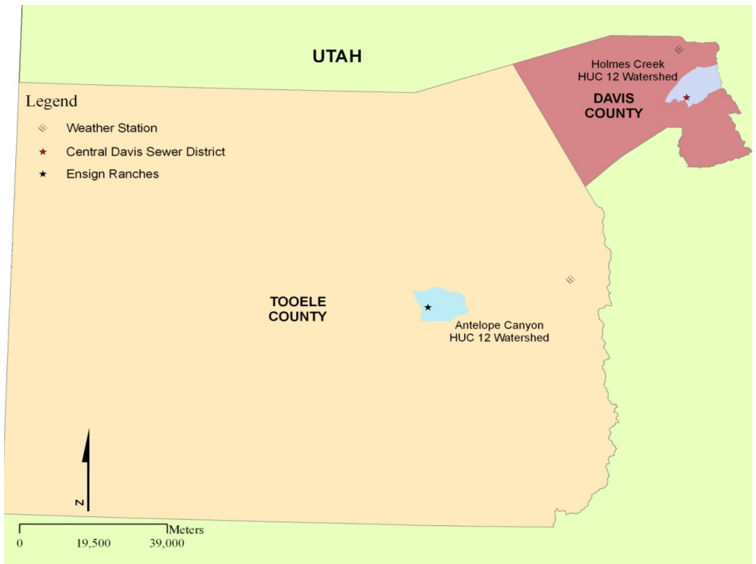


Figure 3 Biosolids land application site location along with weather station location

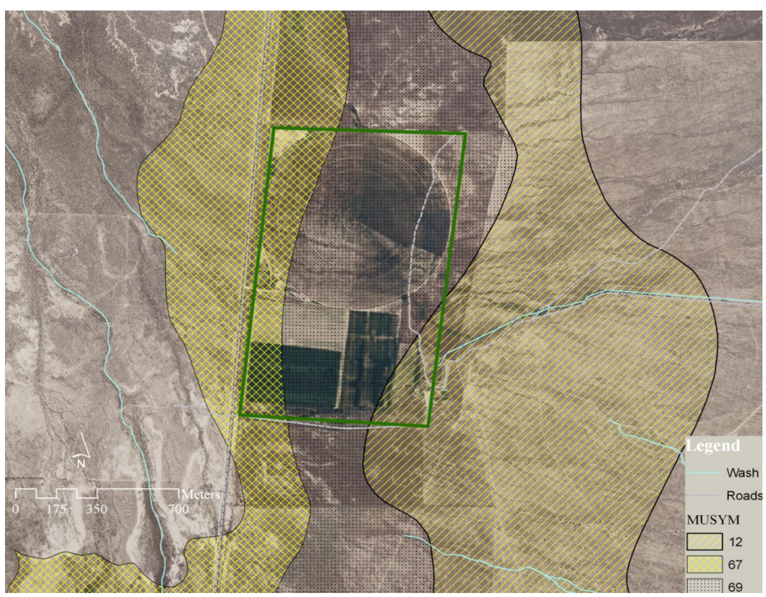


Figure 4 Aerial photograph of Skull Valley biosolids land application site with soil map units

Skull Valley, Utah Biosolids Land Application Site

The Skull Valley, Tooele County, Utah site is a privately held rangeland located approximately 45 miles southwest of Salt Lake City, Utah Figure 4. The zones of application are numbered as shown in Figure 5.

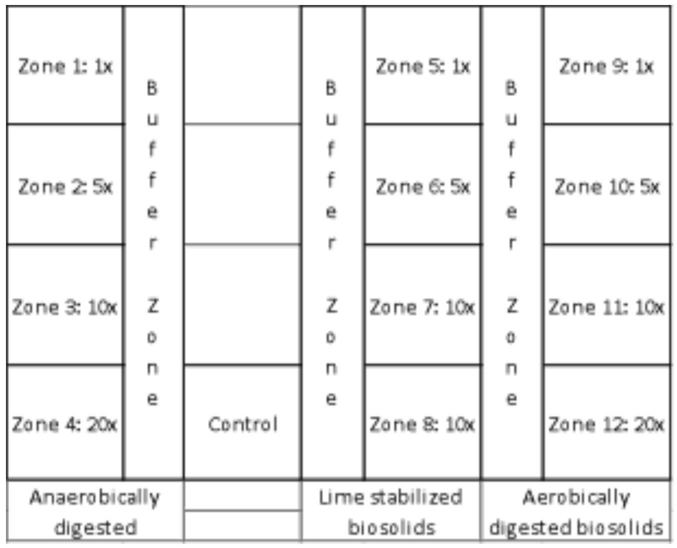


Figure 5 Skull Valley Biosolids land application site zones

Biosolids Application

Disturbed rangelands received land application of biosolids to improve vegetation density and to improve moisture management. Three types of biosolids were applied including lime-stabilized, aerobically digested, and anaerobically digested, on 0.13-ha test plots at rates of up to twenty times the calculated agronomic rates (Table 4 Application rates of biosolids at Skull Valley Site) (VuTran, 2008). Soil samples at depths of 6 inches were collected and analyzed for phosphorus for up to two years after the application (VuTran, 2008).

Table 4 Application rates of biosolids at Skull Valley Site

Agronomic rate	Anaerobically digested	Aerobically digested	lime-stabilized
1x	2.9	3.4	19.7
5x	14.3	17.2	98.6
10x	28.6	34.4	197.3
20x	57.1	68.8	†394.5

Site Characteristics

The field studies were conducted at a private property Ensign Ranch, Skull Valley UT (lat $40^0$27’06’’ and long $112^0$44’42’’W). Sixteen 0.13 ha test plots were selected for biosolids application with each 0.13 ha subplot divided into 144 sections of 3*3 m (10*10 ft.). The test plots were separated by buffer strips. On May 8, 2006 6 plots were chosen in each subplot. Application of lime stabilized and aerobically digested biosolids was in December 2004 while anaerobically digested biosolids were applied in April 2005. The data was measured up to 2 years after biosolids application, with no irrigation in any of the sites. The average annual precipitation was 150 to 200 mm, mean temperature 7 to 10 degrees C (with frost free period of 120 to 160 days) and elevation of 1300 to 1800 m. The application rate of biosolids in the rate was calculated based on the nitrogen requirements of the plants. The percent nitrogen values in applied biosolids are as shown in Table 5 Percent nitrogen in biosolids. Nitrogen demand based agronomic rate was calculated as168.5 kg N per ha (150 lbs-N/ac), with plant biomass of 1123 kg/ha (1000 lbs/ac) 15%N and soil N already present- 112 kg N per ha (100 lb-N per acre). The permeability of the site was moderately rapid and slow runoff potential, hazard of water erosion was slight, and hazard of wind erosion was moderate, rangeland soil is fine sandy loam with a slope of 0 to 5 % and available water capacity of 125 to 165 mm (USDA-Tooele, 2000). Cheat grass, horn seed buttercup and mouse barley were found to be the main vegetation in the sites, the vegetation is considered perennial. The organic matter in surface layer was measured as 0.5 to 1.0 percent and pH of 7.7 to 8.6.

Table 5 Percent nitrogen in biosolids

Biosolids type	Total moisture	% N
lime stabilized	82.5%	0.89%
aerobically digested	6.9%	5.41%
anaerobically digested	80.2%	5.85%

Soil Sampling and Analysis

A majority of total P and plant available P accumulation was found to occur primarily within 0.2 m of the soil surface. Phosphorus leachability to ground water at the sites was calculated to be low based on the molar ratio of [P]/([Al]+[Fe]) and the potential formation of Calcium Phosphate. Different fractions of phosphorus and total phosphorus were measured in the application zones (Table 6). Soil sampling was done for lime stabilized and aerobically digested biosolids receiving sites in May 2005 and anaerobically digested biosolids receiving sites in October 2005, and for the next year in May 2006 (Table 7).

Table 6 phosphorus mass balance in skull Valley study site

p mass balance in lime-stabilized biosolids amended soil				
multiple of	P applied	plant uptake	p residual	p accumulation
agronomic rate	kg/ha	kg/ha	kg/ha	kg/ha
1X	96.75	1.21	95.54	-59.4
5X	483.76	0.52	483.24	160.99
10X	967.53	0.41	967.12	661.57
20X				
aerobically digested biosolid amended soil				
1X	165.46	1.25	164.21	33.49
5X	828.28	1.06	827.22	-29.92
10X	1656.56	1.48	1655.08	398.97

20X	3313.13	1.58	3311.55	621.91
anaerobically digested biosolid amended soil				
1X	71.47	1.31	70.16	131.99
5X	357.34	1.18	356.16	515.94
10X	714.69	0.8	713.89	523.9
20X	1429.37	1.05	1428.32	878.2

Table 7 soil P test, Skull Valley site

		lime-stabilized biosolids	Aerobically digested biosolids	Anaerobically digested biosolids
Multiple of	Depth	Amended sites	Amended sites	Amended sites
agronomic rate	(m)	Olsen P year 2	P-value year 2	P-value year 2
1X	0.2	8.48	6.31	7.44
	0.6	3.81	3.47	3.77
	0.9	3.86	3.6	3.96
	1.2	4.74	4.66	5.04
	1.5	5.12	5.21	5.24
5X	0.2	6.65	6.04	8
	0.6	3.69	3.74	5.58
	0.9	4.43	3.72	4.98
	1.2	4.78	4.58	5.01
	1.5	5.67	5.53	6.62
10X	0.2	12.82	7.63	6.78
	0.6	3.44	3.78	4.13
	0.9	3.68	3.93	4.38
	1.2	5.16	4.49	5.21
	1.5	5.54	5.39	6.23
20x			7.69	8.61
			3.62	3.75
			3.74	4.38
			4.92	5.02
			5.69	5.68

Central Davis, Utah Biosolids Land Application Site

The Central Davis Sewer District land applies anaerobically digested biosolids in publically owned land around it wastewater treatment plant (Figure 6). Farmington bay, the nearest water source to the Central Davis sewer plant and application site receives wastewaters from 7 different wastewater treatment plant directly or indirectly (Wurtsbaugh, 2008).

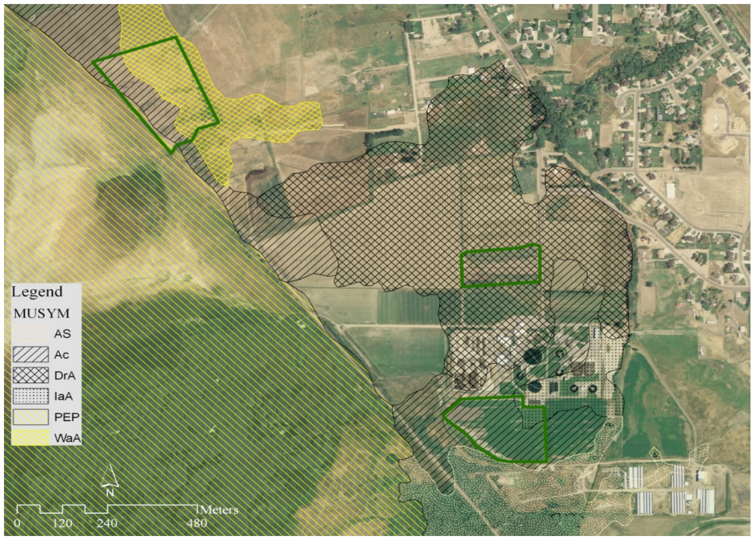


Figure 6 Aerial photograph of CDSD biosolids land application site with soil map units

Biosolids Application

The Central Davis WWTP reuses all biosolids for growing either alfalfa hay or composted and sold to public. Application of biosolids was 290 tons over 130 acres (CDSD). The WWTP produces anaerobically digested biosolids. Approximately 290 tons of biosolids were land applied in 2010.

Site Characteristics

Previous studies have shown that Farmington bay is highly eutrophic and is one of the most polluted water bodies in Utah. It receives most of these waters from the SE end of the lake (Wurtsbaugh, 2008). The above mentioned study also accounted phosphorus loading into the bay. Approximately 130 acres of hay is farmed in the site around the WWTP. The site is divided into 16 zones.

Soil Sampling and Analysis

The CDSD biosolids land application site measured soil test P for all the zones where biosolids were land applied (Figure 7). The total P was correlated with the phosphorus site index at the various sites (similar to the method used by (Mulla, 2000)). A successful correlation should show estimability of PSI and P transport from biosolids application sites. Further, each of the parameters will be compared with the total P value to obtain weighting values.

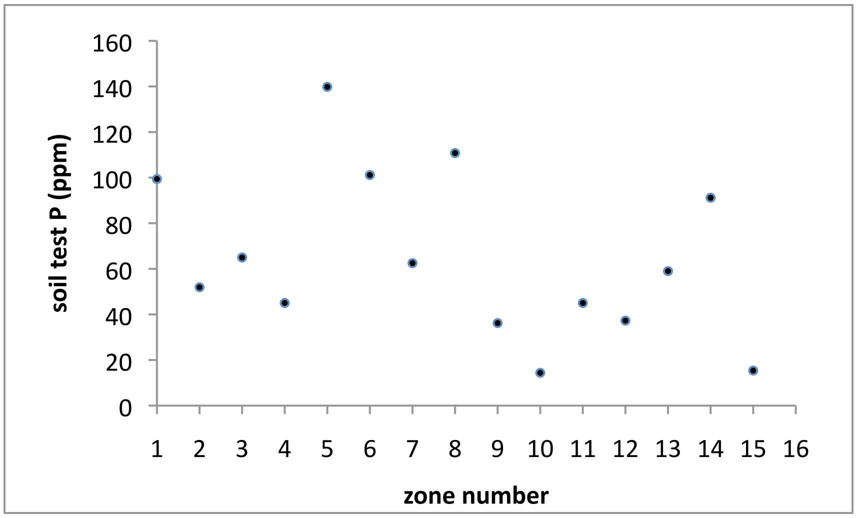


Figure 7 Soil test P, CDSD Site

Description of parameters used for PSI calculations

The list of 8 parameters described in the original NRCS PSI document is used for the PSI calculations.

The following comprehensive list of parameters as obtained from the PSI developed by other states was also considered:

1. soil P test value (available P)
2. Inorganic P application rate (lbs. P2O5/ac/yr.)
3. Organic P application rate (lbs. P2O5/ac/yr.)
4. nutrient application method
5. application timing
6. grazing animals
7. underground outlet systems/ subsurface drainage class
8. Erosion rate (tons/ac/yr.) (WEQ & RUSLE)
9. irrigation erosion (furrow)
10. Soil permeability class (in/hr.)[hydrologic soil group (runoff class)]
11. field slope(%)
12. P application distance to water (ft.)
13. filter strip width (ft.) /vegetative buffers (ft.)
14. impaired, outstanding or critical habitat waters
15. flooding frequency
16. interpretation
17. regulations
18. Source

Since studies have shown that irrigation in Utah has mostly been sprinkler systems, absence of furrows in the system means that the irrigation erosion term in the PSI calculations can be given less weight as compared to the other parameters. Thus the weightage of this factor is reduced by 0.5.

It was also found that sites applying biosolids do not apply additional inorganic fertilizer. The weighting factor of inorganic phosphorus application rate was also reduced by 0.5 based on model fit.

Many studies on PSI by various states have shown that proximity to water as a PSI component was an important factor in the calculation of PSI. This factor was incorporated with a weighting factor of 1, based on the model fit.

Statistical Analysis

1. A linear model was fit of all PSI components with all PSI ratings. This was done to verify the weighting factors for each of the components. It was also used to verify that the appropriate weighting value was given to the "Proximity to water" component in PSI chart.

2. Total P measured in the Skull valley sites were correlated with PSI values calculated for the sites. This was done to show that the risk index actually shows a correlation to the total phosphorus in the sites. This is a good indicator of the estimability of PSI.

3. Total P sediment transport values from EPIC were correlated with total-P and PSI for Skull Valley. This correlation was used to check the accuracy of the EPIC model for prediction of P transport from Skull Valley sites which then was used to show the accuracy of PSI to the actual transport values.

4. Total P sediment transport values from EPIC were correlated with total-P at Central Davis site. This correlation was used to check the accuracy of the EPIC model for prediction of P transport from North Davis sites which then was used to show the accuracy of PSI to the actual transport values.

5. Soluble P values from EPIC were correlated with soil test P and PSI for Skull Valley. It is known that soluble P is a component of soil test P, thus a correlation of the predicted soluble P to the measured soil test P is expected.

6. Soluble P values from EPIC were correlated with soil test P and PSI for Central Davis site. This was also performed to show correlation of site measured values and the model predicted values.

Chapter 4 EPIC Simulations

Inputs and Outputs of Model

Soil Data

The inputs of the model were gathered from readily available sources such as SSURGO database for soils, National Cooperative Soil Survey (NCSS), previous studies, annual reports, weather stations and other literature and are shown in Appendix D CropMAN Input (SSF, Soil Survey Geographic (SSURGO) Database for [607, UT], 2011; SSF, Soil Survey Geographic (SSURGO) Database for [611, UT], 2011). All data were formatted to make the inputs model friendly based on the document that was provided by the developers. Each of the soil data required were entered for the soil layers available (Steglich and Francis 2008). SSURGO allows downloads of data in Access template database and ESRI shapefile formats which were used to generate reports for each specific soil map unit.

Three different soil map units were identified from the SSURGO dataset for the Skull valley site. Each of these map units consisted of 3 soil layers. The Skull Valley land application site was contained within the soil survey area (AREASYMBOL) UT611 and further within three soil map units (MUSYM: 12, 67, and 69). Figure 4 shows the aerial photograph of the site along with soil map units. Six soil map units covered all the zones for Central Davis Sewer District land application site. Each of these map units consisted of 5 soil layers. The Central Davis Sewer District site zones for which the simulation was performed are 2, 11, and 16 and were located in AREASYMBOL UT607. Zone 2 was primarily located in MUSYM Ac, Zone 11 was DrA, and Zone 16 was located in WaA and Ac. The zone naming convention was borrowed from the biosolids annual report (Myers L. , 2011). Figure 6 shows the aerial photograph of the site along with soil map units. The input data extracted from these datasets is provided in the Appendix D CropMAN Input.

Initial labile P concentration in soil was not available for the study area. It is also not a required parameter for a successful run of the model as it can be estimated by the model. As this value was not available, a 20 ppm default value was used for the simulation which is a generally accepted minimum value for plant growth.

Weather

Climate data sets were downloaded from Utah climate center for both Tooele County and Davis County (UCC 2011). Weather stations were identified based on the availability of data for the simulation time period, proximity, and the data collected. Weather station for Tooele County site was Tooele weather station and for Davis County site was Hill AFB, Ogden. The downloaded data was formatted and checked for consistency using CWAnalyzer3 (Steglich and Francis 2008). The minimum data required for both the stations for successful run of CropMAN were year, month, day, maximum temperature, minimum temperature, and precipitation. Optional data input were wind speed.

Fertilizer

Biosolids data was input using both CropMAN interface and Access database. The input data is shown in Table D 1 to Table D 8 in Appendix D CropMAN Input. Three different biosolids were applied at the Skull valley site, anaerobically digested, aerobically digested, and Lime stabilized biosolids. Lime stabilized biosolids was applied at 1, 5, and 10 times the agronomic rate for the December 2004 and April 2005. Both aerobically digested and anaerobically digested biosolids were applied at 1, 5, 10, and 20 times the agronomic rate. All data for the biosolids were applied at Skull valley site was obtained from (Vu Tran, 2008). Central Davis Sewer District site received anaerobically biosolids at agronomic rate for the year 2010 at Zones 2, 11, and 16 (Myers 2011). The raw data obtained from both (Vu Tran, 2008) and Myers (2011) was as Total N, Ammonium N, and Nitrate N. The fractions for inorganic and organic N were calculated based on a modified approach presented in EPA document (WERF 2011). The inorganic fraction was the sum of both the ammonium fraction and the nitrate fraction. The organic fraction was obtained by subtracting the inorganic fraction from the total N. In the case of P, as data was not directly available as inorganic and organic P, it was assumed as 92 % was in inorganic form and 8 % was in organic form based on the study done by Pritchard (Pritchard 2005). The organic matter content was assumed to be 50% by weight which was converted to organic C by dividing 1.72 to account for other elements such as hydrogen, oxygen, nitrogen and other elements (Vu Tran, 2008; Pluske, 2011).

Management and Cropping Systems

CropMAN allows the user to input cropping practices such as dryland or irrigated farming. Dryland farming is practiced at Skull valley site where Cheat grass was primarily grown (VuTran, 2008). Hay and turf grass is grown at the Central Davis Sewer District biosolids land application sites (Myers L. , 2011). Required data includes application times, application rates of biosolids, management practices such as type of irrigation, till or no till.

Phosphorus Mass Balance

Table 8 EPIC simulations shows the actual P losses as for the site as modeled in EPIC. Refer to Appendix E CropMAN Output definition of terms. Figure 8 and Figure 9 show no significant relation between the actual losses and the PSI rating.

Table 8 EPIC simulations for application year

site	Year	FTP (kg/ha)	YLP (kg/ha)	PRKP (kg/ha)	YP (kg/ha)	MNP (kg/ha)	APBC (gm/t)	QAP (kg/ha)	TAP (kg/ha)
SV lime 1x	2005	98.8	0	1.2	0	-6.5	299	0.7	923.3
SV 69 lime 5x	2005	493.6	0	0.8	0.1	-41	1482.25	2.7	4277.5
SV 69 lime 10x	2005	987.2	0	0.7	0.1	-88.7	2894.41	3.7	8269.8
SV 69 aero 1x	2005	165.1	0	1.3	0	-3.7	571.69	0.8	1695.4
SV 69 aero 5x	2005	826.6	0	1.1	0.1	-35	2322.7	4.9	6806.9
SV 69 aero 10x	2005	1653.1	0	1	0.1	-98.6	4406.39	10.2	12806.8

SV 69 aero 20x	2005	3306.2	0	0.9	0.3	-322.7	8069.33	16.6	23236.3
SV 69 anaero 1x	2005	71.5	0	0.9	0	12	226.73	0.3	701.8
SV 69 anaero 5x	2005	357.2	0	0.8	0	-3.2	1001.83	2.1	2936.4
SV 69 anaero 10x	2005	714.8	0	0.7	0.1	-30.2	1933.93	4.3	5620.5
SV 69 anaero 20x	2005	961.5	0	0.7	0.1	-54	2536.73	6	7347.7
CDSD-zone 2	2010	309.2	30	0.5	0	14	728.8	5.1	2954.3
CDSD-zone 11 turfgrass	2010			0	0	78.1	270.76	0	882.3
CDSD-zone 16	2010	0	0	1	0.1	3.4	544.08	3.8	2030

Figure 8 shows the variation in concentrations of total P up to two years after application of biosolids. The increasing trend in total P even after two years after application shows the slow incorporation of phosphorus from biosolids (Hopkins & Ellsworth, Phosphorus Availability with Alkaline/Calcareous Soil, 2005). The trend also shows a proportional increase in phosphorus sorption in soil to the application rates.

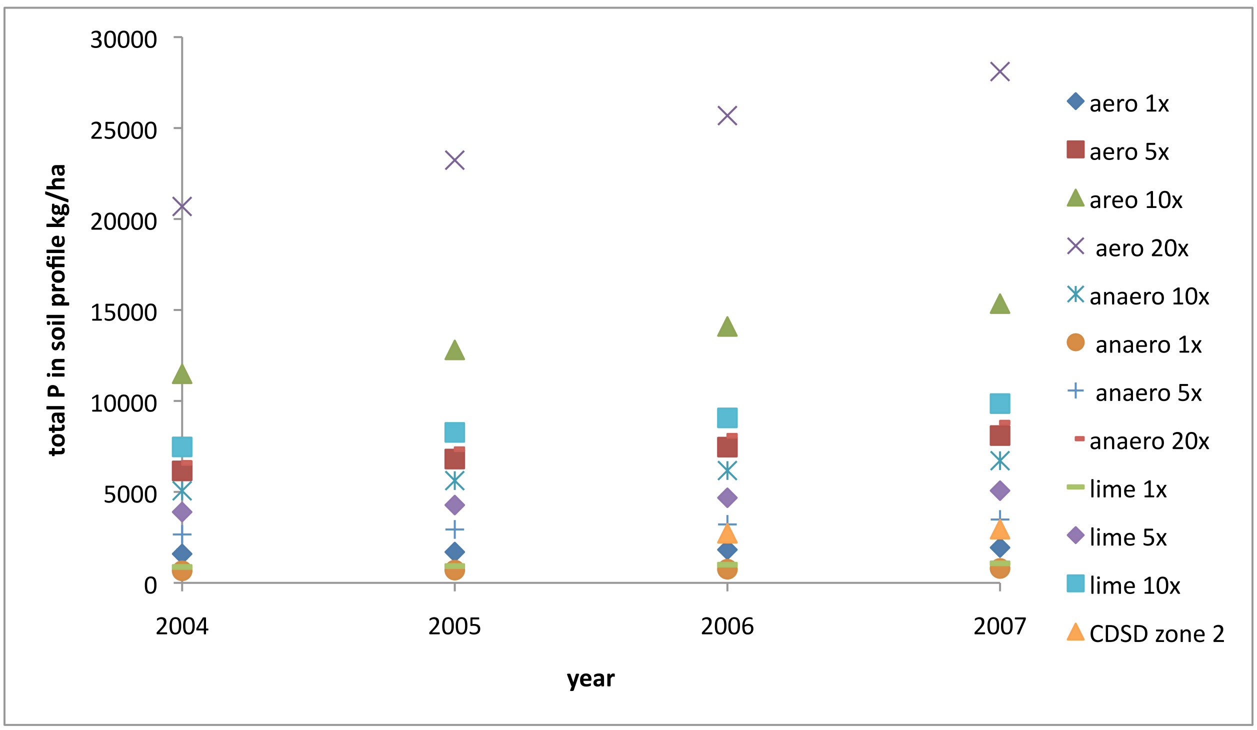


Figure 8 Total soil phosphorus in study sites

Figure 9 shows the phosphorus losses from the biosolids land application sites, with zones receiving aerobically digested biosolids at twenty times the agronomic rate showing the highest soluble P and sediment P loss from the zones. It is verified from this modeling that application of aerobically digested biosolids used has the highest potential for p loss from sites.

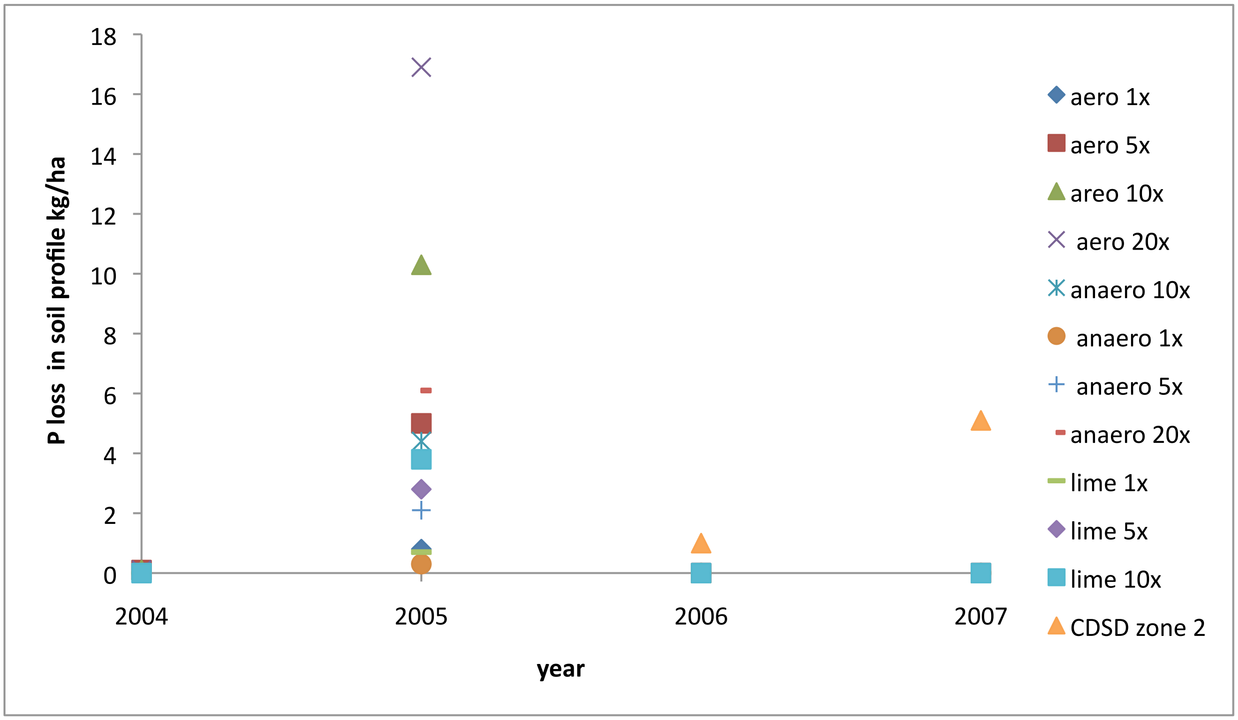


Figure 9 phosphorus losses in study sites

The mineralized phosphorus in study sites is shown in Figure 10. Mineralization of phosphorus in soils is a direct effect of concentrations of soluble P in soils as well as the presence of major P fixers in soils including Fe, Al and Ca. With lime stabilized biosolids that were land applied, had the highest concentrations of Ca and Al. the model simulations show that the zones receiving lime stabilized biosolids at ten times the agronomic rates resulted in the highest mineralized fraction of phosphorus in the soil.

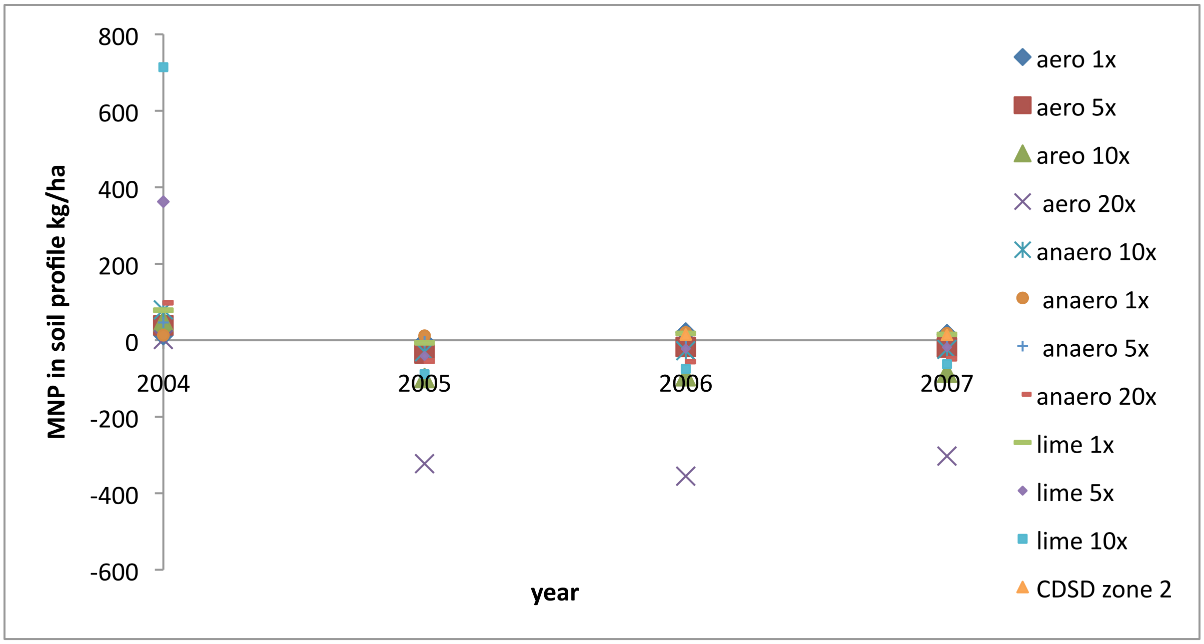


Figure 10 mineralized phosphorus in study sites

Correlation of phosphorus loss from sites with the phosphorus is shown in site indices calculated for the zones are shown in Figure 11. A correlation was seen (r=0.47) and p>0.5 indicating the small sample size. While it was expected that the loss in phosphorus from the sites should have a direct correlation in the rating of the phosphorus site index, a non-relation shows that the phosphorus site index does not account for the losses even after increasing the weighting factor of the soil test P.

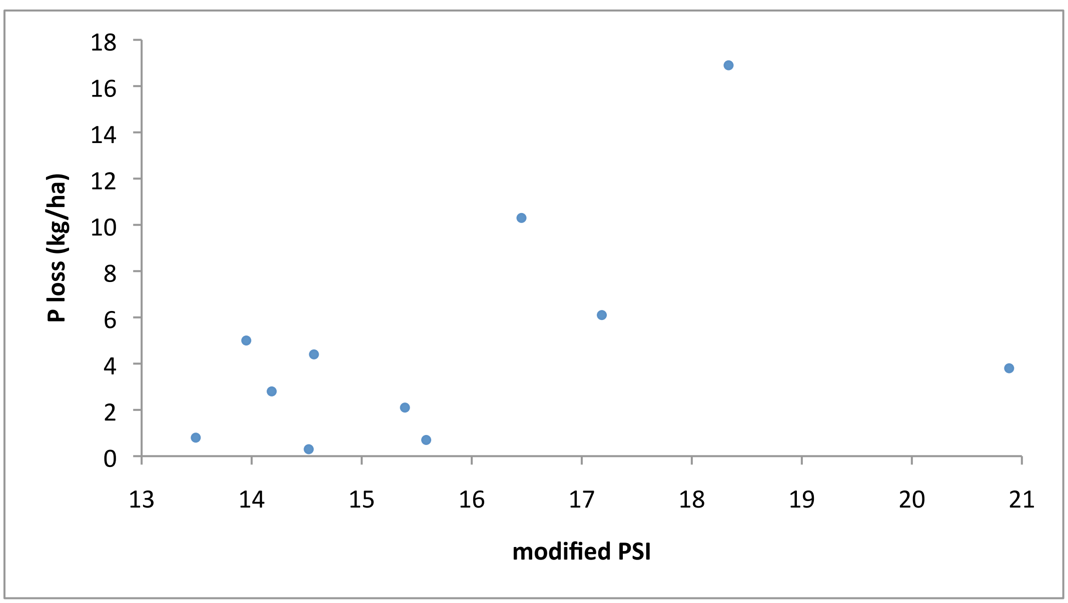


Figure 11 phosphorus loss from sites vs. phosphorus site indices

Figure 12 shows the correlation of phosphorus losses from the zones with the biosolids application rates. R=0.222 indicates a moderate correlation between the application rate and a p<0.5 indicates a significance in the correlation. This moderate correlation is explained due to the concentration of soil P that is already present in the soil before biosolids application, which contribute significantly to the p loss from the zones.

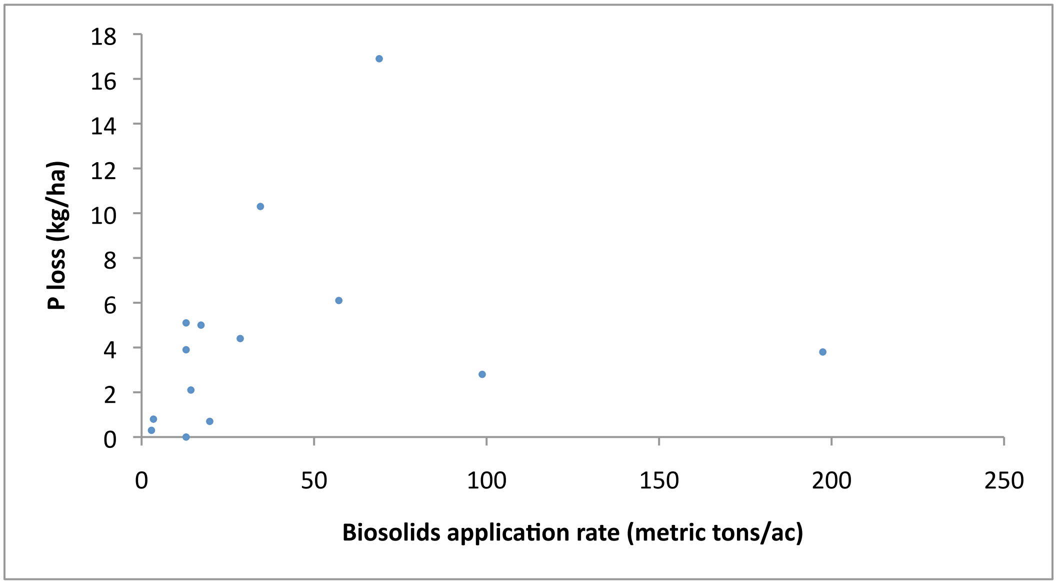


Figure 12 phosphorus loss from sites vs. bisolids application rates

Figure 13 shows the correlation between soil test P and phosphorus loss from zones. A high correlation was observed (r=0.96) and p<0.05 indicated relation of P loss to total P.

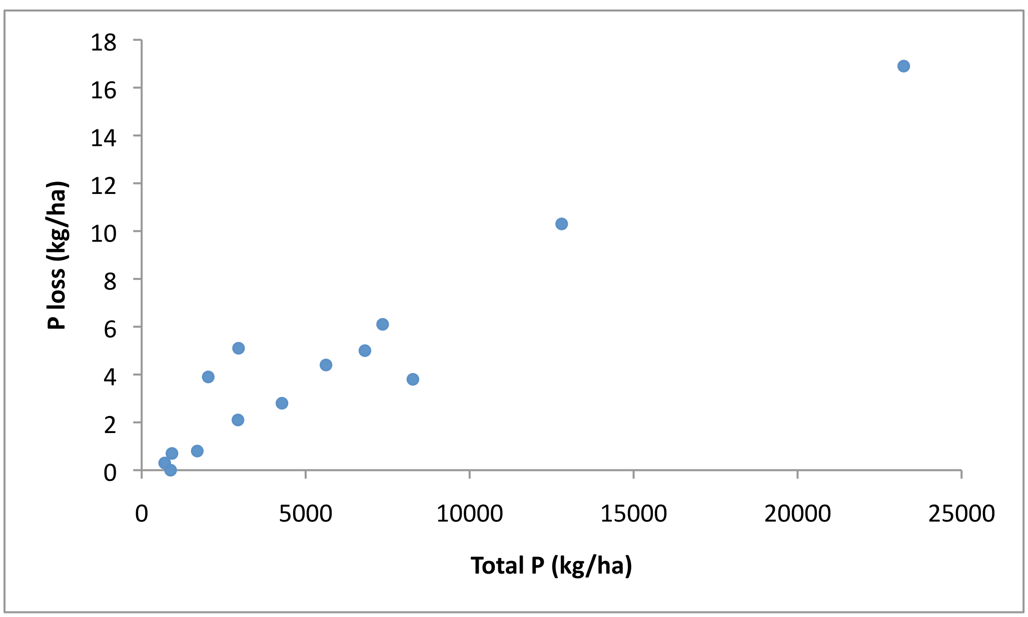


Figure 13 phosphorus loss from sites vs. soil test P values

The sediment P losses modeled from EPIC was compared with the measured soil test P, which showed a significant relation with an F value of 0.009512

A correlation of PSI ratings with the P loss calculated with EPIC shows the linear regression of PSI as a function of P loss is not significant. The relationship, though positive (R^2=0.02) was not significant.

Chapter 5 Phosphorus Site Index

PSI Components

Soil Erosion

In calculating the PSI, soil erosion due to natural precipitation and wind is considered. The Revised Universal Soil Loss Equation (RUSLE) (Eq. 8) in (USDA, 1998) is applied to calculate the movement of soil from the biosolids land application site. The Revised Universal Soil Loss Equation comprises of the following empirical factors.

$$A = R * K * LS * C * P \qquad \dots (1)$$

where:

A: soil loss, metric tons/year
R: rainfall and runoff factor, hundreds of ft.tonf.in.ac^{-1} yr^{-1}
R: product of the total kinetic energy of the storm (E) and its maximum 30 minute intensity
I: represents the RI values for a 22 year period.
K: soil erodibility factor, ton*acre*h*[hundreds of acre.ft.tonf.in]$^{-1}$
K: accounts for the susceptibility of the soil to erosion and the rate of runoff. Soil type (soil name or clay, sand and silt loam percentages) will need to be known.
LS: slope length and gradient factor
L: the slope length factor that is calculated to account for the effect of slope length on erosion. S is the steepness factor which is calculated to account for the effect of slope steepness on erosion.
C: cover and management factor
C-factor accounts for the effect of cropping and management practices on erosion. Each state is divided into zones and C-factor based on crop types and percent cover is available for each state at the state NRCS office.
P: support practice factor
Support practices differentiate between cropland and rangeland or permanent pasture.

The data from the Soil Survey Geographic (SSURGO) database will be used for all the above parameters, with consultation from the State NRCS office.

Table 9 shows the calculation of soil erosion using Equation 1 for Central Davis biosolids land application site and Table 10 shows the soil erosion calculations for the Skull Valley biosolids land application sites. It is noted that the values as obtained from (USDA-Tooele, 2000) have a much lower resolution than the values used for the EPIC simulations.

Table 9 Soil erosion calculation for Central Davis site

Factor	Value	Source
R	20	RUSLE 1998
K	0.29	RUSLE Guidebook (Table 6.17)
LS	0.28	RUSLE Guidebook (Table 6.18)
C	0.5	Dense vegetative cover

P	0.3	strip crop and slope 1 to 2, (USDA)
A	0.243 metric tons/ac	

Soil erosion of 0.24 metric tons/acre is not significant amount of loss from the site. The data obtained from the USDA soils database provides resolution which covers the entire site area, thus the soil erosion value is the same for all zones in the Central Davis site.

Table 10 Soil erosion calculation for Skull Valley site

Factor	Value	Source
R	10	RUSLE 1998
K	0.23	RUSLE Guidebook (Table 6.17)
LS	0.6475	RUSLE Guidebook (Table 6.18)
C	0.005	Dense vegetative cover
P	0.25	strip crop and slope 1 to 2, (VuTran 2008)
A	0.002 metric tons/ac	

Soil erosion of 0.002 metric tons/acre is not significant amount of loss from the site. The data obtained from the USDA soils database provides resolution which covers the entire site area, thus the soil erosion value is the same for all zones studied in Skull Valley site.

Comparison of these soil erosion values with the soil erosion results obtained from the EPIC model, show that there is no significant difference in the erosion values. It is also noted that the EPIC model accounts for both water and wind erosion, while the PSI does not account for wind erosion. Studies have also shown that wind erosion in cultivated sites is not significant.

Irrigation Erosion

In addition to erosion due to natural precipitation, the PSI accounts for soil erosion due to irrigation practices. The magnitude of the following equation is utilized to determine the impact of irrigation erosion on phosphorus movement.

$$\text{Irrigation Erosion Factor} = Q*S \quad \ldots (2)$$

where:

Q = flow rate of water introduced into furrow, in gallons per minute
S = percent furrow slope, in feet per 100 feet, percent

Based on the irrigation erosion factor value, soil erodibility due to irrigation is ranked as follows:

- **Very Erodible Soils:** Soils with silt, or silt loam with < 15% non-montmorillonitic clay, or fine and very fine sandy loam with < 15% non-montmorillonitic clay, or loamy fine sand, or loamy very fine sand.
- **Erosion-resistant Soils:** "Soils with silty clay, clay, or sandy clay texture, weak or massive structure, and mixed or montmorillonitic clay mineralogy, other soils that have medium or coarse blocky structure or coarse granular structure (i.e. natural aggregates >

10 mm) and very firm or firmer rupture resistance class in the moist state in the upper 5 cm of the soil surface”

- **Erodible Soils:** All other soil types. (Modified from (NRCS, 1994).)

As of 2002, about 40% of Utah’s irrigated land was watered through sprinklers, with the rest being furrow or flood irrigated (Hill et al, 2002). Based on fitting a model of the PSI component weighting factors, and considering that sites studied used sprinkler irrigation as well, the weighting factor was reduced from 1.5 to 1.0 based on a model fit of the components of PSI for the study sites.

Runoff Class

The runoff class is determined from the Soil Survey Data based on soil saturated hydraulic conductivity and percent slope (USDA, 1998). Loss ratings and weighting factor (0.5) are used from Table 2 PSI using NRCS Guidelines based on NRCS guidelines. Appendix C Soil Erosion Estimation, Utah shows the R values used for the state of Utah.

Skull Valley had moderately permeable soils and hydraulic conductivity (USDA), and a moderate site slope between 0% and 5% at the highest point.

Central Davis had low slopes of 0 to 2% and soils of low permeability of (<0.06 in/hr.

Proximity to water factor of PSI is classified as > 1000 feet from water or ditch, 500-1000 feet from water or ditch, appropriate setback applied (< 500 feet), downstream edge of field adjacent to water or ditch, for low medium and high respectively. Skull Valley site does not have water sources at least 1000 feet from the sites. The closest water body to the Central Davis biosolids land application site is the Farmington bay, which is more than 1000 feet from the site, and thus not considered a risk. Studies have shown that 1000 feet is sufficient distance to be considered out of risk of P transport for the state of Utah (UMARI).

The term proximity to water was an addition to the original 8 components of PSI as dictated by the NRCS guidelines. The weighting factor of 1 for the proximity to water component was obtained based on the fitting the model of the parameters calculated for PSI for both the sites.

Soil Phosphorus Concentration

To gauge and characterize the potential risk of phosphorus impacts to local surface waters from biosolids land application activities, the soil phosphorus concentration must be estimated. The PSI requires that the “plant available” as well as total phosphorus concentration in soil be estimated. Olsen P test is specifically used for the state of Utah for its alkaline soils. The available P data from Olsen P test will be used as input for this parameter.

Table 7 shows Olsen P test values for different zones in Skull Valley. The values for all zones are either moderate or low available P, according to classification in Table 2.

Central Davis soil test P values are shown in Figure 14. The values are seen to be in the very high range (from Table 1), which is explained as due to repeated application of biosolids over multiple years.

Phosphorus Fertilizer Application Rate and Method

Although the application of supplemental chemical fertilizer on biosolids land application sites rarely occurs, the PSI calculations provides an opportunity to capture this value as part of the overall phosphorus loading to the site. The amount of potential phosphate P2O5 contained in biosolids must be estimated or measured to address this requirement of the PSI evaluation.

Skull Valley biosolids land application sites were used as test sites and received many times the required amount of biosolids calculated from the crop nitrogen requirement rate. Central Davis biosolids land application site produced alfalfa hay and turf grass, based on requirements and thus the application rates are followed based on plant requirements of nitrogen.

Figure 14 shows that a good correlation exists between the soil test P and the biosolids application rates with r=0.95 and $p<0.05$.

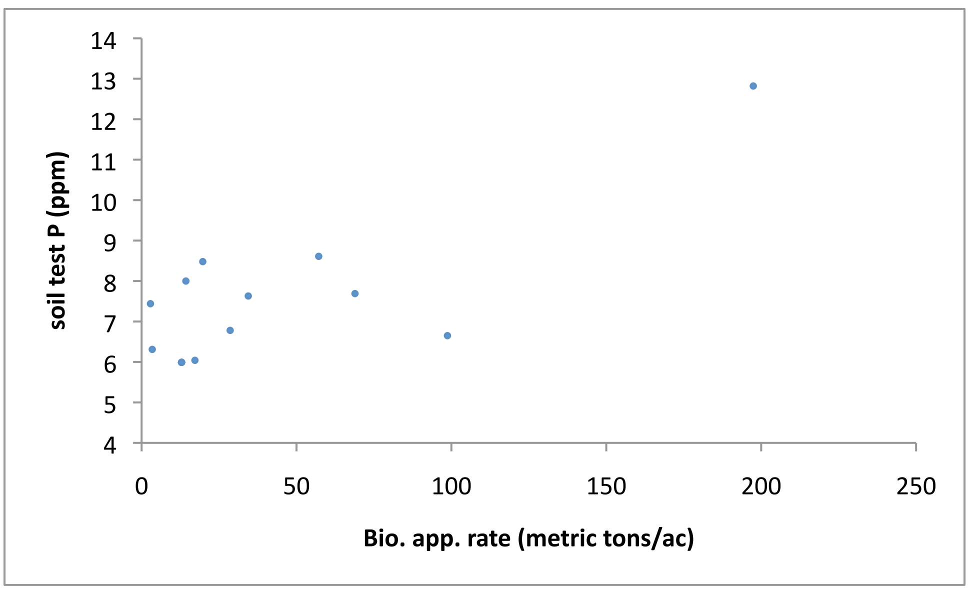


Figure 14 soil test P vs. biosolids application rates

PSI Calculations

Table 11 lists study zone characteristics and phosphorus site indices for these sites. Using the interpretation Table 9 and Table 10, it is seen that all but two PSI values are in the low range, indicating low risk of p transport. Zones 6 and 7 that received lime stabilized biosolids at 5 and 10 times the calculated agronomic rate show a medium risk of p transport from these sites.

Table 11 Phosphorus Site Indices

Site, year	Zone	Biosolids applied	Application rate (metric tons/ac)	Soil Test P	PSI
Skull Valley 2004	5	Lime stabilized	19.75	8.48	8
Skull Valley 2004	6	Lime stabilized	98.73	6.65	15
Skull Valley 2004	7	Lime stabilized	197.45	12.82	16
Skull Valley 2004	9	Aerobically digested	3.44	6.31	8
Skull Valley 2004	10	Aerobically digested	17.22	6.04	8
Skull Valley 2004	11	Aerobically digested	34.44	7.63	9
Skull Valley 2004	12	Aerobically digested	68.88	7.69	11
Skull Valley 2005	1	Anaerobically digested	2.86	7.44	8
Skull Valley 2005	2	Anaerobically digested	14.29	8	8
Skull Valley 2005	3	Anaerobically digested	28.59	6.78	8
Skull Valley 2005	4	Anaerobically digested	57.17	8.61	9
Central Davis 2010	2, 11, 16	Anaerobically digested	12.9	5.99	9

Table 12 uses the rating categories modified from NRCS guidelines, and depend on the types of P management practices in Utah (UMARI). Table 12 shows the rating categorization of the phosphorus site index.

Table 12 Interpration table for UT-PSI

PSI rating	**Interpretation**
<8	**VERY LOW** potential for P movement from the field. Little or no probability of risk to surface or ground water. Potential for annual spreading of biosolids (e.g. Central Davis Sewer District practices)
8-14	**LOW** potential for P movement from the field. The chance of organic material and nutrients' getting into surface or groundwater is low. Buffers, setbacks, improved irrigation and biosolids application practices, runoff containment/control alone or in combination will decrease chances of runoff.
15-32	**MEDIUM** potential for P movement from the field. The chance of organic material and nutrients getting to surface or ground water is very likely. A combination of buffers, setbacks, improved irrigation practices, and application practices, will lower the impact. Winter spreading and runoff results in high chance of P losses.

>32	**HIGH** potential for P movement from the field and an adverse impact on surface and ground water. Biosolids should not be applied unless best management practices are in place. Biosolids should not be spread during the winter.

A linear model was fit of all PSI components with all PSI ratings. This was done to verify the weighting factors for each of the components. It was also used to verify that the appropriate weighting value was given to the "proximity to water" component in PSI chart.

A linear model was fit for the 9 components of PSI, including the proximity to water component. The model was fit to obtain the weighting factor for the proximity to water component, and to adjust the weighting factors for the irrigation erosion and inorganic P application rate components. The summary of weighting factors is shown in Table 13.

Table 13 Weighting factors comparison

PSI component	Weighting factor (old)	Weighting factor (new)
Soil erosion	1.5	1.5
Irrigation erosion	1.5	1
Runoff class	0.5	0.5
Proximity to water	NA	1
Soil P test	1	1
Biosolids application rate	1 (organic P)	1
Biosolids application method	1 (organic P)	1
Inorganic P fertilizer application rate	0.75	0.25
Inorganic P fertilizer application method	0.5	0.5

PSI Weighting Factors model fit

Total P measured in the Skull valley sites were correlated with PSI values calculated for the sites. This was done to show the correlation between risk index and the total phosphorus in the sites. This is a good indicator of the estimability of PSI.

Correlation of Total P and PSI for Skull Valley

Total P was correlated with the PSI ratings for Skull Valley and showed a relatively significant relationship (R^2=0.7073117). Table 14 shows the modified PSI interpretation. Weighting factors have been modified as detailed in Table 13. The proximity to water component has been included. Soil P test loss ratings are adjusted according to the 590 Nutrient Standard Guidelines for Utah. These ranges are also reflected in the P-fertilizer and biosolids application rates.

Table 14 Utah PSI Interpretation

Site Characteristic (Weighting Factor)	**Phosphorus Loss Rating (Value)**				
	NONE (0)	**LOW (1)**	**MEDIUM (2)**	**HIGH (4)**	**VERY HIGH (8)**
Soil Erosion (1.5)	Not Applicable	<5 Tons/Ac	5-10 Tons/Ac	10-15 Tons/Ac	>15 Tons/Ac

Irrigation Erosion (1)	Not Applicable	Tail water Recovery Or Qs<6 For Very Erodible Soils Or Qs<10 For Other Soils	Qs>10 For Erosion Resistant Soils	Qs>10 For Erodible Soils	Qs>6 For Very Erodible Soils
Runoff Class (0.5)	Negligible	Very Low Or Low	Medium	High	Very High
Soil P-Test (1.0)	Not Applicable	<4 ppm	4 – 50 ppm	50 – 100 ppm	>100 ppm
Proximity To Water (1)	> 2640 feet	2640 - 1000 Ft. From Water Or Ditch	500-1000 Ft. From Water Or Ditch	Appropriate Setback Applied1 (< 500 Ft)	Downstream Edge Adjacent To Water Or Ditch
P-Fertilizer App. Rate (0.25)	None Applied	<4 ppm	4-50 ppm	50-100 ppm	> 100 ppm
P-Fertilizer App. Method (0.5)	None Applied	Placed With Planter Deeper Than 2 Inches	Incorporated Immediately Before Crop	Incorporated > 3 Months Before Crop Or Surface Applied < 3 Months Before Crop	Surface Applied > 3 Months Before Crop
Biosolids App. Rate (1.0)	None Applied	<4 ppm	4-50 ppm	50-100 ppm	> 100 ppm
Biosolids App. Method (1.0)	None	Injected Deeper Than 2 Inches	Incorporated Immediately Before Crop	Incorporated > 3 Months Before Crop Or Surface Applied < 3 Months Before Crop	Surface Applied To Pasture, Or > 3 Months Before Crop

PSI is calculated as:

PSI=SE LR*(1.5) + IE LR*(1) + RC LR*(0.5) + Ptest LR*(1) + PW LR*(1) + IPrate LR*(.25) + IPmethod LR*(.5) + OPrate LR*(1) + OPmethod LR*(1)

Where PW is the proximity to water component of PSI.

Appendix A Skull Valley PSI Calculations and Appendix A Skull Valley PSI Calculations summarize the PSI calculations and the PSI factors for all biosolids land application zones in the Skull Valley and Central Davis sites.

Chapter 6 Conclusions and Engineering Significance

Best Management Practices

For sites that have high or very high probability of phosphorus transport, the distance from the site to the nearest water body will be evaluated. If below 1000 feet, a list of best management practices for mitigating the risk of surface water quality impairment shall be developed.

Following Recommendations were either followed at the sites, or are necessary to reduce the transport of P from the sites.

1. erosion-control blankets: though not widely used, the blankets have shown to reduce runoff in high slope sites (Urroz, 1996)
2. Silt filter fences: these are also usually used in high slope sites to prevent erosion till sufficient rooting has developed.
3. Diversion terraces: this is a commonly used farming practice where strip or contour cropping cannot be done due to high slope length, thus terraces are built.
4. Sedimentation ponds: are built to hold runoff water and to allow settling.
5. Contour buffer strips: also a common farming practice similar to strip cropping, where the vegetation is permanent.
6. Field borders: a strip of crop that surrounds the field. This reduces the sediment load in water runoff from field
7. Riparian forest buffers: permanent buffers of trees and shrubs that are closer to the surface water than to the sites.
8. Vegetative barriers: narrow strips of densely growing plants planted perpendicular to the contour.
9. Grassed waterways: channels built to transport water that have vegetation to reduce velocity of water, preventing soil erosion
10. Stream bank protection: for protection of stream banks from erosion.

The study sites in both Skull Valley and Central Davis have buffer strips that are used to control the sediment from erosion.

Chapter 7 Conclusions

Current NRCS guidelines for phosphorus management prevent application of biosolids over private lands for more than one year. The limits on soil phosphorus are easily crossed after a single application of biosolids.

The phosphorus site index model modified for the state of Utah estimates that the phosphorus losses from the study sites allow for application of phosphorus for more than one year. While the Skull Valley biosolids land application site was a study site that received rates that were much higher than the calculated nitrogen based agronomic rates, the zones that received normal application rates as well as the Central Davis biosolids land application sites show that application of biosolids over multiple applications poses a lower risk of phosphorus loss.

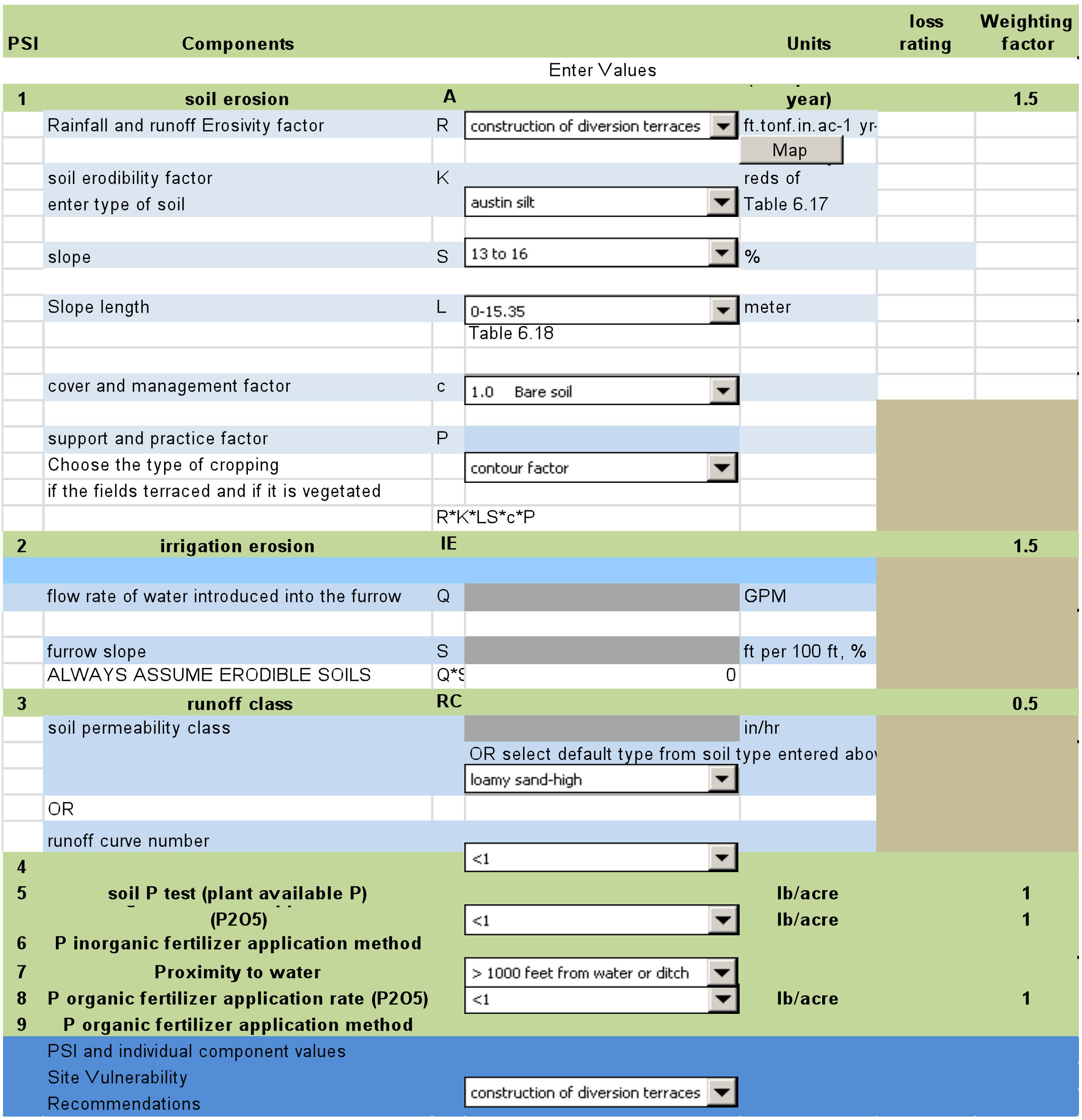
The EPIC model used to simulate phosphorus losses from the study sites did not correlate well with the phosphorus site index ratings. The weighting factors for the components of phosphorus site were adjusted based on the available data in the study sites to further increase accuracy of the phosphorus site index.

P values for the various correlations of the measured values in study sites compared with the EPIC model show that sufficient data was not used. The PSI model's accuracy can be further increased by addition of more study sites to the EPIC model and corresponding adjustments of the weighting factors used in the PSI worksheet.

The PSI worksheet developed will make it easier for biosolids application and phosphorus management for private land owners as well as biosolids appliers. The worksheet has been designed considering ease of use and data not easily available for the sites (e.g. soils, weather etc.) are already stored in the worksheet database.

Utah PSI Calculator Worksheet

By integrating the calibrated algorithms from the PSI model with an evaluation of nearest water body distance, a simple calculator tool specific for defensible phosphorus decision-making at biosolids land application sites shall be developed.



PSI	Components		Enter Values	Units	loss rating	Weighting factor
1	**soil erosion**	**A**		**year)**		**1.5**
	Rainfall and runoff Erosivity factor	R	construction of diversion terraces	ft.tonf.in.ac-1 yr-		
				Map		
	soil erodibility factor	K		reds of		
	enter type of soil		austin silt	Table 6.17		
	slope	S	13 to 16	%		
	Slope length	L	0-15.35	meter		
			Table 6.18			
	cover and management factor	c	1.0 Bare soil			
	support and practice factor	P				
	Choose the type of cropping		contour factor			
	if the fields terraced and if it is vegetated					
		R*K*LS*c*P				
2	**irrigation erosion**	**IE**				**1.5**
	flow rate of water introduced into the furrow	Q		GPM		
	furrow slope	S		ft per 100 ft, %		
	ALWAYS ASSUME ERODIBLE SOILS	Q*S	0			
3	**runoff class**	**RC**				**0.5**
	soil permeability class			in/hr		
			OR select default type from soil type entered abov			
			loamy sand-high			
	OR					
	runoff curve number		<1			
4						
5	**soil P test (plant available P)**			**lb/acre**		**1**
	(P2O5)		<1	**lb/acre**		**1**
6	**P inorganic fertilizer application method**					
7	**Proximity to water**		> 1000 feet from water or ditch			
8	**P organic fertilizer application rate (P2O5)**		<1	**lb/acre**		**1**
9	**P organic fertilizer application method**					
	PSI and individual component values					
	Site Vulnerability		construction of diversion terraces			
	Recommendations					

Figure 15 Utah-PSI worksheet

References

Basta, J. P. (1996). Reduction of Excessive Bioavailable Phosphorus in Soils by Using Municipal and Industrial Wastes. *J. Environ. Qual*, 25:1236-1241.

BREC. (August 2006). *User's Guide for CroPMan (Crop Production and Management Model* (Version 4.0 ed.). College Station, Texas: Blackland Research and Extension Center.

BREC, T. (2003). *WetherImport: A Weather Analyzer for Production Agriculture, User's Guide Version 3.2.*

BREC, T. A. (2011). *CroPMan* . Retrieved july 16, 2011, from http://cropman.brc.tamus.edu/.

Cardon, G. E., Kotuby-Amachar, J., hole, P., & Koenig, R. (2008, May). *Understanding Your Soil Test Report*. (Utah State University) Retrieved May 31, 2011, from extension.usu.edu: http://extension.usu.edu/files/publications/publication/AG_Soils_2008-01pr.pdf

CDSD. (n.d.). *WWTP General Information*. Retrieved July 3, 2011, from Central Davis Sewer District: http://www.cdsewer.org/District_Info/district_info.html

Chad A. Kinney, E. T. (2006). Survey of Organic Wastewater Contaminants in Biosolids Destined for Land Application. *Environ. Sci. Technol.* , 40, 7207-7215.

D. L. Forster, R. P. (2000). EPIC modeling of the effects of farming practice changes on water quality in two Lake Erie watersheds. *Journal of Soil and Water Conservation*, vol. 55 no. 1 85-90.

Edwards, D. R. (1993). The Moore's Creek BMP effectiveness monitoring project . *ASAE*, Pap. 932085.

Gary M. Pierzynski, J. T. (2005). *Soils and environmental quality.* Boca Raton, FL : CRC Press.

Gerik, T. J. (2006). *User's Guide: CroPMan (Crop Production and Management) Model, Version 4.0.* Temple, TX: Blackland Research and Extension Center.

H. A. Elliott, G. A. (2002). Phosphorus Leaching from Biosolids-Amended Sandy Soils. *J. Environ. Qual.*, 31:681–689.

Hopkins, B., & Ellsworth, J. (2005). Phosphorus Availability with Alkaline/Calcareous Soil. *Western Nutrient Management Conference*, (pp. Vol. 6. 88-93). Salt Lake City, UT.

http://www.nrcs.usda.gov/technical/ECS/nutrient/pindex.html. (n.d.).

Ippolito, J. A. (2007). Biosolids Impact Soil Phosphorus Accountability, Fractionation, and Potential Environmental Risk. *J. Environ. Qual.*, 36: 764–772.

Jones, C. A. (1984). A Simplified Soil and Plant Phosphorus Model: I. Documentation1. *Soil Sci. Soc. Am. J.* , 48(4): 800-805.

Kinney, C. A., Furlong, E. T., Zaugg, S. D., Burkhardt, M. R., Werner, S. L., Cahill, J. D., et al. (2006). Survey of Organic Wastewater Contaminants in Biosolids Destined for Land Application. *Environ. Sci*, 40, 7207-7215.

Lowell Busman, J. L. (2009, July). (University of Minnesota) Retrieved from http://www.extension.umn.edu/distribution/cropsystems/DC6795.html

M. A. Saleque, U. A. (2004). Inorganic and Organic Phosphorus Fertilizer Effects on the Phosphorus Fractionation in Wetland Rice Soils. *Soil Sci. Soc. Am. J.*, 68:1635–1644.

Maguire, R. O. (2000). Phosphorus Fractionation in Biosolids-Amended Soils Relationship to Soluble and Desorbable Phosphorus. *Soil Sci. Soc. Am. J.*, 64: 2018–2024.

Maguire, R., Sims, J., & Coale, F. (2000). Phosphorus Fractionation in Biosolids-Amended Soils: Relationship to Soluble and Desorbable Phosphorus. *64*(2018-2024).

McFarland, M. J. (2001). *Biosolids Engineering.* New York: McGraw-Hill Professional Engineering.

Md. Abul Kashem, O. O. (2004). Extractable phosphorus in alkaline soils amended with high rates of organic and inorganic phosphorus. *Can. J. Soil. Sci.*

Mulla, A. B. (2000). Evaluation of the Phosphorus Index in Watersheds at the Regional Scale. *Journal of Environmental Quality*, Vol. 30 No. 6, p. 2018-1025.

Mullins, G. L. (1997). *Phosphorus accumulation and loss from Alabama soils receiving poultry litter.* Auburn, Ala.: Alabama Agricultural Experiment Station, Auburn University.

Myers, L. (2011). *Biosolids Annual Report UT 0020974.* . Kaysville, UT: Central Davis Sewer District.

Myers, L., & Houston, J. (January 2006). *An Evaluation of Phosphorus Loading.* Central Davis Sewer District.

Natural Resource Conservation Service. (1995a). *A Phosphorus Assessment Tool, Idaho Technical Note Tri-Water Quality #1.* Boise, Idaho: Agri-Chemical Management for Water Quality.

NRCS. (1994, August). *The Phosphorus Index: A Phosphorus Assessment Tool.* Retrieved July 3, 2011, from Natural Resources Conservation Service: http://www.nrcs.usda.gov/technical/ecs/nutrient/pindex.html

O. C. Nwoke, B. V. (December 2003). Assessment of labile phosphorus fractions and adsorption characteristics in relation to soil properties of West African savanna soils. *Agriculture, Ecosystems & Environment*, Volume 100, Issues 2-3, 285-294.

Peters, J. M. (1996). Reduction of excessive bioavailable phosphorus in. *25*(1236-1241).

Pierzynski, G. M. (2000). *Soils and Environmental Quality* (Vol. 480 p.). Boca Raton Florida: CRC Press.

Pluske, W. D. (2011). Organic carbon.

Pritchard, D. L. (2005). *Phosphorus bioavailability from land-applied biosolids in south-western Australia.* Curtin University of Technology. Muresk, Institute.

S.W. Chung, P. W. (March 1999). *Validation of EPIC for Two Watersheds in Southwest Iowa.* Ames, IA: Center for Agricultural and Rural Development, Iowa State University.

Shober, A. L. (2006). Characterization of Phosphorus Species in Biosolids and Manures Using XANES Spectroscopy. *J. Environ. Qual.*, 35: 1983–1993.

Sims, A. L. (2002). Phosphorus Restrictions for Land Application of Biosolids. *Journal of Environmental Quality*, Vol. 32 No. 6, p. 1955-1964.

Sims, C. J. (2002). Phosphorus Forms in Biosolids-Amended Soils and Losses in Runoff: Effects of Wastewater Treatment Process. *J. Environ. Qual*, 31:1349–1361.

Sims, R. M. (2001). Relationships between Biosolids Treatment Process and Soil Phosphorus Availability. *J. Environ. Qual.* , 30:1023-1033.

Sinclair, A., & Johnstone, P. (1995). Ability of a dynamic model of phosphorus to account for observed patterns of response in a series of phosphate fertilizer trials on pasture. *Fertilizer Research*, 40: 21-29.

SSF, S. S. (2011). *Soil Survey Geographic (SSURGO) Database for [607, UT].* Natural Resources Conservation Service, United States Department of Agriculture.

SSF, S. S. (2011). *Soil Survey Geographic (SSURGO) Database for [611, UT].* Natural Resources Conservation Service, United States Department of Agriculture.

Staff, T. (2007, 6 9). *iPhone: Who's the real manufacturer? (it isn't Apple)*. (textyt.com) Retrieved from http://texyt.com/iphone+manufacturer+supplier+assembler+not+apple+00113.

Steglich, E. a. (2008). *Creating a WinEPIC / CroPMan / WinAPEX Database and Related Files for Your Area Using the Texas Central Database.* Agrilife Research.

Su J, W. H. (2007). Fractionation and Mobility of Phosphorus in a Sandy Forest Soil Amended with Biosolids. *Env Sci Pollut Res*, Vol. 14, No. (7) 529–53.

Thompson, Y. S. (2000). Phosphorus Sorption, Desorption, and Buffering Capacity in a Biosolids-Amended Mollisol. *Soil Sci. Soc. Am. J.*, 64:164–169.

Torbert, H. A. (2008). EPIC Evaluation of the Impact of Poultry Litter Application Timing on Nutrient Losses. *Communications in Soil Science and Plant Analysis* , 39(19): 30.

UCC, U. C. (2011). *Climate data sets.* Retrieved July 15, 2011, from http://climate.usurf.usu.edu/

Urroz, E. G. (1996). *Hydromulches vs. Erosion Control Blankets in Hillsides.* California Land-Scaping.

USDA. (1998). Revised Universal Soil Loss Equation. *Agriculture Handbook Number 703*.

USDA-Tooele. (2000). *Soil Survey of Tooele Area, Utah.* Tooele, UT: United States Department of Agriculture- Natural Resources Conservation Service.

USEPA. (1995). *Process design manual: Land application of sewage sludge and domestic.* Cincinnati, Ohio.: The U.S. Environmental Protection Agency.

Valentino-DeVries, J. (2011, January 25). *Verizon Sees Huge iPhone Demand. Will Supply Keep Up?* (The Wall Street Journal) Retrieved from http://blogs.wsj.com/digits/2011/01/25/verizon-sees-huge-iphone-demand-will-supply-keep-up/.

Vasquez, I. R. (2008, May 1). Impact of Land-Applied Biosolids on Forage Quality And Water Movement During Rangeland Restoration Activities. *All Graduate Theses and Desertations*, p. Paper 89.

Vu Tran, M. A. (2008). Nutrient Mobility From Biosolids Land Application Sites. Logan.

VuTran, M. A. (2008). *Nutrient Mobility From Biosolids Land Application Sites.* Logan: http://digitalcommons.usu.edu/etd/74.

Wang, X. R. (2006). SOIL & WATER - Evaluation of EPIC for Assessing Crop Yield, Runoff, Sediment and Nutrient Losses from Watersheds with Poultry Litter Fertilization. *Transactions of the ASAE* , 49(1): 47.

WERF, W. E. (2011). *Appendix A. Calculating biosolids application rates for agriculture.*

Williams, J. R. (1990). The Erosion-Productivity impact calculator (EPIC) model: A case history. *Philosophical Transactions: Biological Sciences.*, 329(1255): 421-428.

Williams, J. R. (1990). The Erosion-Productivity Impact Calculator (EPIC) Model: A Case History. *Philosophical Transactions: Biological Sciences*, 329(1255): 421-428.

Wurtsbaugh, W. (2008, November 20). *Nutrients & Eutrophication in Farmington Bay and the Great Salt Lake.*

Xiao-Lan Huang, Y. C. (2008). *Chemical Fractionation of Phosphorus in Stabilized Biosolids.* J. Environ. Qual.

Zhang, H., & Kovar, J. L. (June 2009). Fractionation of Soil Phosphorus. In *Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters.* Virginia Tech University.

Appendices

Appendix A Skull Valley PSI Calculations

Table A 1 Skull Valley PSI calculated for zones receiving lime-stabilized biosolids

PSI lime stabilized	**weighting** factor	**value**	**units**	**Loss** Rating	**PSI**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	8.48	mg/kg	2	2
inorganic p app rate	0.25	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	0.106425	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	6.65	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha		0
inorganic p app method	0.5	0	NA		0
organic p app rate	1	0.532136	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	12.82	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha		0
inorganic p app method	0.5	0	NA		0
organic p app rate	1	1.064283	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**

Table A 2 Skull Valley PSI for zones receiving aerobically digested biosolids

PSI aerobically digested	**weighting factor**	**value**	**Units**	**Loss Rating**	**PSI**

soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	6.31	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	0.182006	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	6.04	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	0.911108	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	7.63	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	1.822216	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	7.69	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0

inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	3.644443	metric ton/ha	2	2
organic p app method	1	surface applied	NA	4	4
Site PSI					**11**

Table A 3 Skull Valley PSI for zones receiving anaerobically digested biosolis

PSI anaerobically digested	**weighting factor**	**value**	**units**	**Loss Rating**	**PSI**
PSI anaerobically digested	weighting factor	value	units	Loss Rating	PSI
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	7.44	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	0.078617	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	8	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	0.393074	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	6.78	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0

inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	0.786159	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**
soil erosion	1.5	0.001861563	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5	NA	LV	1	0.5
Proximity to water	1	>1000	feet	1	1
soil p test	1	8.61	mg/kg	2	2
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5	0	NA	0	0
organic p app rate	1	1.572307	metric ton/ha	1	1
organic p app method	1	surface applied	NA	4	4
Site PSI					**10**

Appendix B Central Davis Site PSI Calculations

Table B 1 Central Davis zone 2

CDSD PSI anaerobically digested biosolids	weighting factor	Value	Units	Loss Rating	PSI
soil erosion	1.5	0.2436	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5		LV	1	0.5
soil p test	1	75.98666667	mg/kg	4	0
Proximity to water	1	>1000	feet	1	1
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5		NA	0	0
organic p app rate	1	12.9	metric ton/ha	1	0
organic p app method	1	incorporated before cropping	NA	2	2
Site PSI					5

Table B 2 Central Davis zone 11

PSI anaerobically digested	weighting factor	value	Units	Loss Rating	PSI
soil erosion	1.5	0.2436	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5		LV	1	0.5
soil p test	1		mg/kg		0
Proximity to water	1	>1000	feet	1	1
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5		NA	0	0
organic p app rate	1		metric ton/ha		0
organic p app method	1	incorporated before cropping	NA	2	2
Site PSI					5

Table B 3 Central Davis zone 16

PSI anaerobically digested	weighting factor	value	Units	Loss Rating	PSI
soil erosion	1.5	0.2436	metric tons/ac	1	1.5
irrigation erosion	1.5	0	kg/ha-yr	0	0
runoff class	0.5		LV	1	0.5
soil p test	1		mg/kg		0
Proximity to water	1	>1000	feet	1	1
inorganic p app rate	0.75	0	metric ton/ha	0	0
inorganic p app method	0.5		NA	0	0
organic p app rate	1		metric ton/ha		0
organic p app method	1	incorporated before cropping	NA	2	2
Site PSI					5

Appendix C Soil Erosion Estimation, Utah

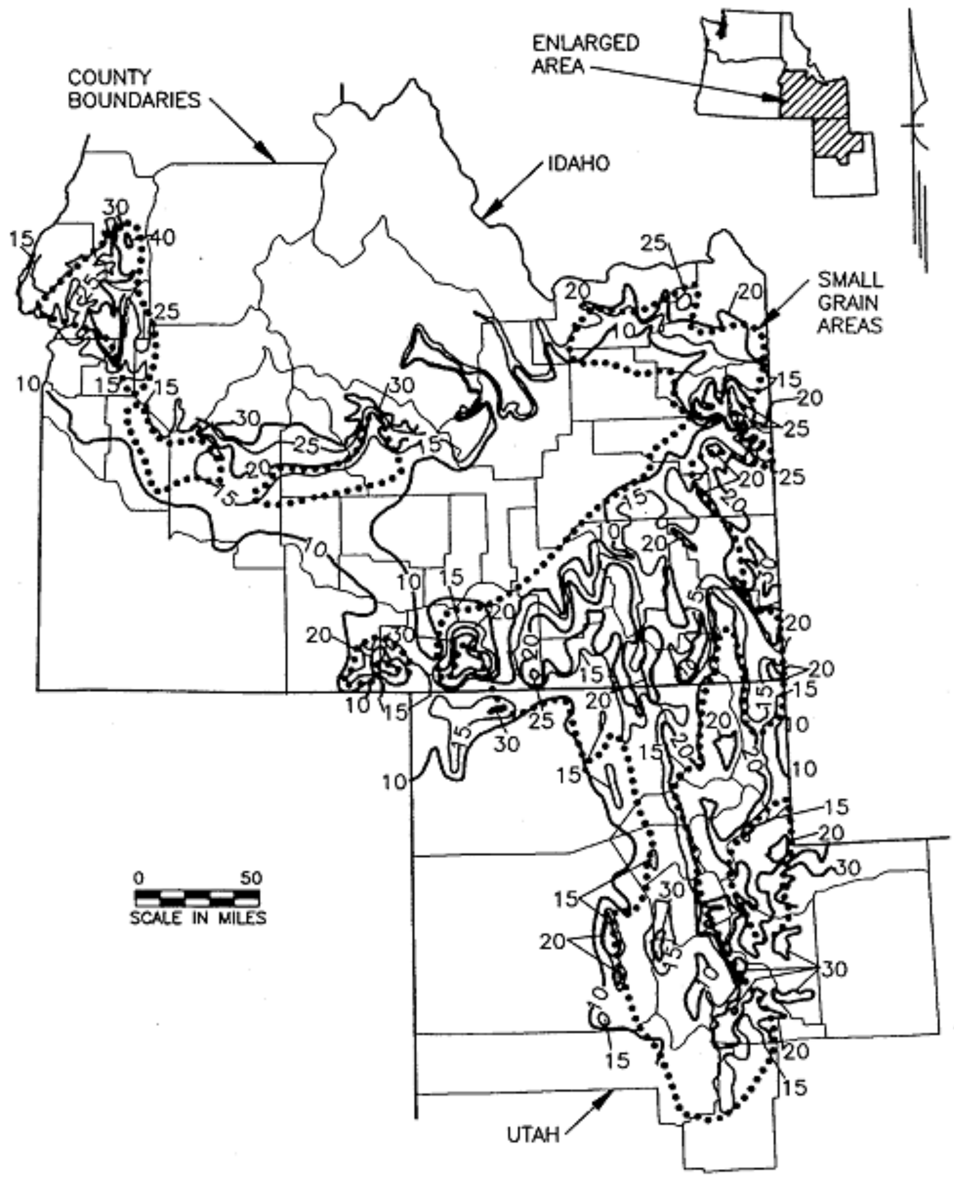


Figure C 1Precipitation map (inches) used to calculate Rainfall runoff factor (R_{eq}) in southern Idaho and Utah for small-grain area of Northwestern wheat and range region. Precipitation units in inches. (RUSLE Figure 2-14)

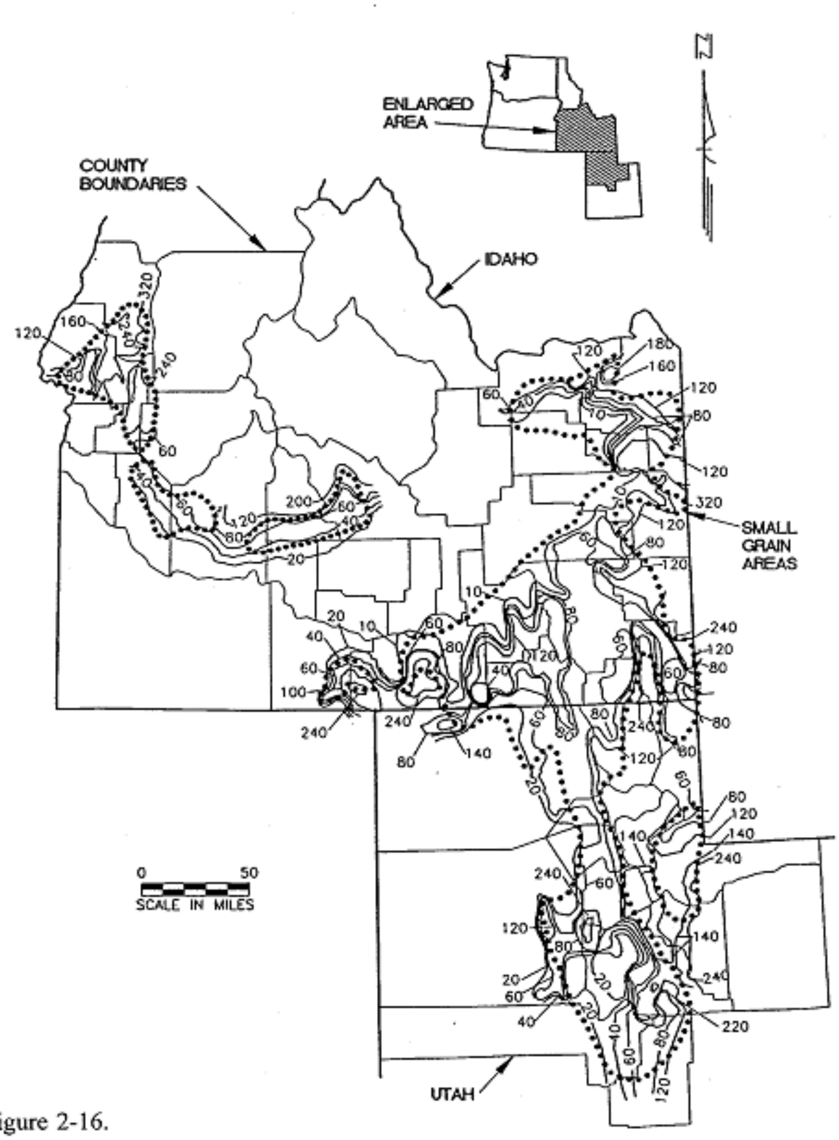


Figure 2-16.

Figure C 2 R_{eq} for cropland areas of southern Idaho and Utah in and adjacent to Northwestern Wheat and Range Region (Note: Some irregular contour intervals are used to preserve clarity). R_{eq} units are hundreds ft. tonf.in(ac.h)$^{-1}$ (RUSLE, Fig 2-16)