DEVELOPMENT OF A MANAGEMENT FOCUSED DECISION SUPPORT TOOL FOR OKEECHOBEE BASIN BEEF CATTLE AGROECOSYSTEMS

By

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To my father for all the support he has always shown me; to my mother for being a tremendous influence in my life, I would like to dedicate my thesis and all my achievements at the University of Florida. Her memory and blessings have brought me this far.

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Agricultural enterprises require resource management that involve many trade-offs within a complex ecological and financial environment. As an example enterprise within South Central Florida, the MacArthur Agro-Ecology Research Center (MAERC) located on the Buck Island Ranch (BIR) in Lake Placid Florida has a major objective to optimize its long term sustainability in both ecological and economic facets. MAERC/BIR combines a research facility with a commercial-scale, beef cattle enterprise (10,300 acres) to explore the role of long-term ecological and social dynamics within sub-tropical grazing systems (www.maerc.org).

In order to maintain long term viability and sustainability, a balance between ranch profitability and reduction of non point source pollution effects needs to be established and studied. A possible solution to this challenge is to create a Decision Support System (DSS) for beef cattle enterprises. Such a DSS could serve to communicate simulation results and metrics effectively to the ranch operators, whose focus would be on profitability, as well as the researchers and conservationists, whose focus would be on limiting the effects of non point source pollution. Thus, the objective of this research project is to design and construct a decision support model of a beef cattle ranch system to simulate selected beef cattle and ranch

management operations on a southern Florida beef cattle enterprise and to explore the management decisions with respect to water resource factors such as runoff and nutrient loading.

The *Questions and Decisions* ™ (QnD™) model system was created to provide an effective and efficient tool to integrate ecosystem, management, economic and socio-political factors into a user-friendly model/game framework. This model is a unique and new development since no other model before has modeled scenarios on a ranch-scale. The model is also good in that it is more than just a hydrological model but also a decision support tool for managers with a user interface that helps them in real-time decision making. The QnD model links spatial components within geographic information system (GIS) files to the abiotic (climatic) and biotic interactions that exist in an environmental system. QnD can be constructed with any combination of detailed technical data or estimated interactions of the ecological/management/social/economic forces influencing an ecosystem.

The specific QnD version has been developed for the BIR (QnD:BIR) using the conceptual diagram which shows the integrated ecological and economic factors at the ranch-scale. QnD:BIR uses elements of the Standardized Performance Analysis (SPA) method applied to BIR to simulate elements of beef cattle production and economic dynamics. QnD:BIR uses simplified water and phosphorous dynamics at a monthly time step generated from the long term research from southern Florida beef and dairy cattle research. QnD:BIR utilizes existing geographic information systems (GIS) coverages and monitoring data available from the MAERC/BIR facility. QnD:BIR was tested on environmental data from BIR for the period of 2000 - 2003 for sixteen experimental pastures including both improved and native pastures. Specifically, QnD:BIR simulation results of monthly runoff, phosphorus load and forage production were compared with comparable field-scale data. Given the coarse monthly time step, simulations of these factors were generally acceptable for use in the whole ranch simulations. Given potential climate data for the area, specific scenarios were constructed to test different management scenarios in terms of P loading and cattle production metrics. The development of QnD: BIR provides a useful and modular system, capable of running various scenarios depending on the setup for simulating both environmental and enterprise functions, within an easy to use graphical interface with the ability to move cows and manage the enterprise hands-on. Further model development and simulation could be expanded to allow more detail in cattle response to temperature and surface water availability.

Qnd: BIR is a simple model that uses empirical relations with acceptable levels of accuracy (and a Nash-Sutcliffe coefficient of at least 0.5 mostly). The model also takes into account rainfall, water table depth, temperature, and soil characteristics for its hydrology and phosphorus cycle.

However, since the model uses empirical relations, it cannot be applied in conditions that differ vastly from the conditions present in BIR. Also, due to its simple nature it does not take into account factors such as light, for ET, or drainage within and across pastures in the ranch and into the canals.

Considering the significant positive qualities and certain limitations of the model, it can be said that the model is to be used more as a guideline to point the manager in the right direction for decision making than as a tool to provide exact values or measures for runoff or phosphorus load in the long term.

CHAPTER 1
INTRODUCTION

Management of agricultural enterprises often occurs within the context of complex environmental and societal challenges including elements of economic, management and political viewpoints as well as the often-explored technical perspectives. The quality of these agro-ecological systems is significantly affected by the rapid growth in the state's population over the last three and a half decades and concerns over non-point source pollution (2006 Integrated Water Quality Assessment Report-*FDEP, 2006*).

As an example, beef cattle operations in south central Florida are concerned with long-term sustainability and viability under increasing regulatory pressures. Adding to this existing challenge is the uncertainty of climate and environmental drivers to agroecosystems. Decision Support Systems (DSS) linking water resources and agriculture should be cognizant of the intersecting and sometimes conflicting goals of profitability, non-point source pollution effects and adaptive management. Recent advances in the climate sciences, including improved capabilities to forecast seasonal climate, have provided increased capabilities for developing useful decision support tools in service of specific agriculture, forestry, and water resources management (SECC, 2007). These decision tools should communicate simulation results to decision-makers or stake-holders in their own language and metrics whenever possible. Three fundamental questions arise when investigating water resource management within beef cattle enterprises.

1. What decisions are currently made that effect runoff, water quality on beef cattle ranches?

2. How accurate do forecasts have to be to be useful for beef cattle operations and environmental regulators?

This research addresses some of these questions by exploring the role of management-focused, agro-ecosystem models. The objectives of this research project are the following:

1. Design and construct a decision support/scenario-based model of a beef cattle ranch using the QnD model system to simulate selected beef cattle and range management operations on a southern Florida beef cattle operation.

2. Test and calibrate the model using climate, hydrology, soil and forage monitoring data from representative pastures.

3. Explore the impact of scenarios on management decisions with respect to water resource factors such as runoff, nutrient loading, calf production and basic revenue/cost dynamics.

The MacArthur Agro-Ecology Research Center (MAERC) located on the Buck Island Ranch (BIR), Lake Placid Florida provides a unique setting for production-related, agro-ecological research. MAERC/BIR combines a research facility with a commercial-scale, beef cattle enterprise (10,300 acres) to explore the role of long-term ecological and social dynamics within sub-tropical grazing systems (www.maerc.org). Recent multi-disciplinary research efforts at Buck Island Ranch (Swain *et al.*, 2007; Arthington *et al.*, 2007; Tanner and McSorely, 2007; Capece *et al.*, 2007) have provided a useful dataset of climate, hydrological, nutrient, vegetation, herbivore and production/economic data for further integration and model development.

Organization of this Thesis

In addition to the introduction, this thesis research is divided into four chapters and a technical appendix. Chapter 2 provides a review of several items relevant to the research: an overview of the Buck Island Ranch monitoring effort; a brief review of the existing hydrological and nutrient modeling approaches that have been used in similar environmental systems; a detailed look into some of the related object oriented and decision support concepts and an overview of the QnD modeling system. In Chapter 3, a detailed design of the QnD Modeling effort within Buck Island Ranch has been described along with the methodology for model calibration and testing. An analysis of the model's structure and the methodology used to model the given system is presented, along with the results of model calibration and testing. The following chapter (Chapter 4) presents the results of QnD model testing on specific pastures (improved and native) within BIR. Chapter 5 provides an overall summary and lessons learnt from the modeling effort as well as potential next steps. The technical appendix provides additional results and background for greater clarification in terms of object designs and model performance on specific pastures.

CHAPTER 2
LITERATURE REVIEW

This chapter provides a review of the concepts and background used in developing a decision support system for a beef cattle enterprise. An overview of Buck Island ranch, the research site is given in order to help put things into perspective, along with a brief history of a sample set models that have been developed to date. Following this review, a section is provided that helps the reader to understand the need for a more object oriented model and the object orientation concepts, which are discussed in detail. The object oriented review section is followed by a detailed analysis of the QnD model and its overall structure, hence providing for an overall foundation of the research project.

Study Site: Buck Island Ranch

Non-point source pollution is a major cause of concern in the south Florida water systems. Lake Okeechobee is one of the largest and most important water bodies of this region and a very popular site for research studies analyzing the effect of non-point source pollution on a typical beef cattle agro-ecosystem (Martinez 2006, Yang 2006, Pandey 2007). According to Pandey (2007), the MacArthur Agro-ecology Research Center, Buck Island Ranch (BIR, 4168, ha), Lake Placid, Florida, USA (27^{o} 09'N, 81^{o} 12'W), shown in Figure 2-1, was chosen for a research site since it is representative of the subtropical, wet-prairie agro-ecosystem that exists in the Okeechobee watershed. For the proposed objective of this research too, this site would be well suited. Buck Island ranch presents a diverse and rich ecological setting, due to its coupling of sparse forests and wetlands in the midst of a commercial cattle ranch owned by the John D. and Catherine T. MacArthur Foundation (Arthington et al., 2007; Swain et al., 2007). The ranch area itself is at the center of a tributary basin of Lake Okeechobee, the Indian Prairie/Harney Pond Basin, which has been drained for better pasture over several years (Arthington et al., 2007;

Swain et al., 2007, Pandey 2007). This ranch enterprise has been the center of research for almost a decade due to the willingness and interest of the ranchers themselves to limit the effects of non-point source pollution on the Lake Okeechobee watershed.

A majority of the current and past research projects at Buck Island ranch have focused on the experimental pastures (Summer 1- 8, Winter 1-8) and to evaluate the effectiveness of the Best Management Practices (BMP's) to control the non-point pollution effects(Pandey 2007, Yang 2006). However, the BMP's mainly focus on reducing phosphorus loads in the region, and since BIR is primarily a commercial cattle ranch, one of the main management goals is to optimize the amount of beef production per unit area of land, or in other words improve the productivity of the enterprise. This trade-off balance tends to be the responsibility of the ranch managers to maintain. Cattle rotation is one of the practices that are commonly done at the ranch in order to maintain optimal feed for the cattle. The rotations are designed such that a cattle herd spends the majority of its time on the improved summer pastures (May – October), where the forage available is Bahiagrass (*Paspalum notatum*), which has a higher forage quality. Pandey (2007) explains the movement of cattle to be done due to two reasons : firstly, summer pastures are fertilized (NH4NO3 – 56 Kg N/ha) (Arthington et al., 2007) in spring and, therefore, have better forage quantity and quality compared to winter pastures which have never been fertilized (Swain et al., 2007). Secondly, winter pastures are less intensively drained and as a result they are regularly flooded during the rainy season in summer. For the stocking rate experiment of 1998 – 2003 (Swain et al, 2007), the summer and winter experimental pastures were chosen to gauge the effect of different cattle stocking on the environment.

Experimental Pastures

The pastures in the ranch are divided into seasonal pastures depending upon where the cows are placed seasonally. The seasonally demarcated pastures fall mainly into two categories:

summer pastures which tend to be improved, and winter pastures which tend to be native grass pastures.

The summer pastures are eight approximately 20 ha (range = 19.0 to 22.1 ha) pastures where in the cattle are stocked during the summer months. These pastures are well drained and the major forage growth in this region is Bahiagrass (*Paspalum notatum*). Bahiagrass is generally considered to be higher in nutritional value than the native species of grass that grows the winter or unimproved pastures (Kunkle 2001).

The winter pastures similarly are eight experimental pastures of approximately 32.2 ha (range = 30.3 to 34.1 ha). The forage on these pastures is not regulated and hence Bahiagrass is not the major forage species in the region. Compared to the summer pastures, the winter pastures are not as well drained and retain water during large rain events.

A network of shallow surface canals and drains carry all of the runoff water into the Harney Pond Canal and then onward into Lake Okeechobee. As a result, monitoring these pastures is essential to control the addition of phosphorus to the lake.

Overview of Past and Current Models

Buck Island ranch has been the object of multiple research studies involved in hydrological and nutrient model development. Many scientists and students from the University of Florida and other institutions have conducted several research studies at the site. Stocking rate experiments conducted during 1998 – 2003 have lead to several studies being conducted based of the data collected from the experiment.

One such study involving the integration of Ranch Forage Production, Cattle Performance, and Economics in Ranch Management Systems by Arthington et al, (2007) indicated that stocking rates had a large effect on total production and profitability. However, stocking rates had minimal to no effect on forage utilization or cattle performance. With no offsets in improved calving percentages, weaning weights or other measures of livestock performance, the inevitable outcome of lower stocking rate is impaired profit potential (Arthington et al., 2007). Overall changes in stocking rate has a direct, one-to-one relationship with ranch revenues. If stocking rate effects surface water quality, there is a tradeoff between water quality improvement and profits from breeding cows.

Moreover, an analysis of the soil phosphorus, cattle stocking rates, and water quality for the region (Capece et.al., 2007) indicated better effectiveness of approaches focused on decreasing phosphorus inputs and decreasing movement of accumulated soil phosphorus into surface runoff would be more effective than approaches focused cattle management for reducing P loads in surface runoff from cattle pastures. It also showed that the stocking rate had no measurable effect on nutrients in surface runoff during 5 years of stocking treatments (Capece et.al., 2007).

A Brief Summary of Hydrological and Nutrient Models

This section provides a history of agricultural modeling and presents an overview of a few of the past and current models that have been developed for various landscapes in an attempt to help familiarize readers with the history of modeling and put into better perspective this modeling effort. Over the last few decades a variety of ecological and biological models have been developed. The objective of this research entails the study of hydrology, nutrient movement and forage growth, along with beef cattle enterprise management, and a few modeling efforts focused on some of these fields are looked at in this section.

The Hydrological models can be classified on a scale ranging from distributed physical - based to the lumped conceptual models. In the early 1970s the U.S. Environmental Protection Agency (EPA) began sponsoring a series of water quality models in response to the Clean Water Act, hence a majority of hydrological models used presently were developed during this time.

Early conceptual hydrological models used a representation of basic laws of hydrology using differential equations and empirical algebraic equations for modeling different processes (Yang, 2006). Some of the more popular models include Stanford Watershed Model (Crawford and Linsley, 1966), the SSARR (Streamflow Synthesis and Reservoir Regulation) model (Rockwood et al., 1972), Sacramento Soil Moisture Accounting Model (Burnash 1973), the HBV model (Bergstrom 1976), the tank model (Sugawara et al., 1976), the Xinanjiang model (Zhao et al. 1980), HEC-1 (Hydrologic Engineering Center, 1981) and the HYMO (Williams and Hann, 1983), CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Knisel, 1980) and the CREAMS derived GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) (Leonard et al., 1987). Recently, the dynamic changes in the modeled areas are being explained by study in conceptual models of soil depletion, redistribution and moisture replenishment. (Arnold and Fohrer, 2005, Yang 2006).

The next class of models is more physically-based than the lumped conceptual models, which enable the more detailed representation of the physical watershed and hence require simpler structure and fewer parameters. Some examples of semi-distributed physically based models include SWAT (Soil and Water Assessment Tool) (Arnold et al., 1993) , SWIM (Soil and Water Integrated Model) (Krysanova et al., 1998, 2005), AGNPS (Agricultural Non- Point Source pollution model) (Young et al., 1989), TOPMODEL (a TOPography based hydrological MODEL) (Beven and Kirkby, 1979) and ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation) (Beasley and Huggins, 1980), SDSM model (Singh 2001) with their application varying from examining water quality to assessing the effectiveness of BMP's on runoff and nutrient loads of the given watershed.

A third class of models is the completely physically-based distributed models. Some examples of physically based models are MODFLOW (McDonald and Harbaugh, 1988), MIKE SHE (Refsgaard and Storm, 1995) and GSSHA (Ogden 2001).

Overview of Forage Models

Forage models have been developed through time with varying complexities, ranging from a simple empirical model like the Miami model (Leith 1975) to the more complex physiological models like the DSSAT (Jones 2003). The model developed mainly depends on the location for which it was developed and the types of forage it was dealing with. Yang (2006) has reviewed the structure of additional forage models such as PAPRAN (Seligman 1981), CENTURY model (Parton et al. 1987) ELM (Innis, 1978), ERHYM-II (White, 1987), GEM (Hunt et al., 1991), CCGRASS (Verberne, 1992) and GEMT (Chen and Cougheour, 1994) and the Hurley Pasture Model (Thornley and Cannell, 1997).

All the models discussed in the above section were used extensively in their time and are applicable today. However, as the depth and computational requirements of modeling complex ecosystems increases, the technical competence required by the model also compounds exponentially. This raises the need for a complete rewrite of the program code for any and every small change in the conditions or a change in the site on which it is being applied. A requirement arises for a system that is capable of adapting to highly complex processes that might change from one location to the other without having to rewrite the model, i.e. the issue of portability.

Object Oriented Systems Development

Object oriented systems are beginning to develop as a practical solution to the issue of model reusability. In recent times, the complex and highly computational model development is turning to object orientation concepts to better develop the model and at the same time keep the design simplistic for example the ACRU 2000 (Kiker et al. 2006). The most recent version of the

ACRU (Agricultural Catchments Research Unit) (Schulze et. al, 1989) was reconstructed to be an object oriented model that described its landscape in terms of Components, Processes and Data. The ACRU 2000 (Kiker et al. 2006) is developed in Java and has proven to be highly extendable. Several modeling efforts have been conducted using this model in the south Florida region and the research site of Buck Island Ranch. (Martinez 2006; Yang 2006; Pandey 2007).

The following discussion highlights the various facets of object orientation and its application in the world of modeling. The use of object orientation in modeling increased in the early 1990's with several models being developed using the concept (Matsinos et al 1994, Mooij, 1996).

Object Oriented Programming (OOP) originated as a development platform for physical modeling in Simula-67 programming language. However, in the mid 1990's, it developed as the dominant programming methodology, largely due to the influence of C++. In the past decade, with the rise in popularity of Java programming language, the use of OOP concepts has become more common, perhaps more importantly because of its implementation using a virtual machine that is intended to run code unchanged on many different platforms. This feature of portability of code is also being introduced now by Microsoft into the .Net framework.

The "magic" quarks (Armstrong, 2006) of object orientation exists in the main components of it namely, inheritance, encapsulation, polymorphism and abstraction along with objects, instances and classes. The following sections provide some additional detail of these concepts in an attempt to understand their application within environmental decision support systems.

A class is the basic unit in OOP. Classes are real world groups, which interact with each other through relationships. A class can be a species, a group, any unit that has common properties and implements common processes (Robson 1981, Rosson 1990). It can also be defined as a set of objects that share a common structure and common behavior (Booch 1994).

An object, on the other hand, is an instance of a class (Booch 1994) and can be anything from fish to cows to grass to anything that is being modeled. It is important to understand that an object refers to the individual but not the whole group. It is further explained by Armstrong (2006) as an individual, identifiable item, either real or abstract, which contains data about itself and descriptions of its manipulations of the data. An object of a class has all the properties of that class and all of its parent classes. For example, an individual cow has all the properties and processes of the cow species class as well as the mammal class which would be the parent class. This concept of parent and child classes brings us to the first property of OOP, inheritance.

Inheritance was introduced as a part of the development of OOP in 1967 in the Simula programming language. (Dershem, 1995). Some literature also inclines towards the idea that inheritance is the only unique feature introduced by OOP (Henderson-Sellers 1992). Inheritance has been defined as a mechanism by which object implementations can be organized to share descriptions (Wirfs-Brock, 1990) and also by Armstrong (2006) as a mechanism that allows the data and behavior of one class to be included in or used as the basis for another class. Inheritance signifies the property that any given class can be derived from another class, and it in turn ‘inherits’ all of the properties and the processes of that parent class. This property continues all the way to the highest level of the hierarchy (Budd, 1991; Silvert, 1993). Such a hierarchical structure ensures that only very specific properties need to be specified for each individual object and it inherits most of the higher level properties from its parent class. This reduces the complexity of the code and increases the simplicity of the design itself (Moooij and Boersma, 1996).

Another important reason for the simplicity of design of object oriented models is the encapsulation property of OOP. It is described as a process used to package data with the functions that act on the data or more commonly as a property that hides the details of the object's implementation so that clients access the object only via its defined external interface (Wirfs-Brock 1990). Encapsulation is the containment of all of the processes and properties required and performed by the object of a class, within that class or its parents. This reduces the coding overhead on the object. For example, a cow or a fish having all of its properties and processes within itself and allows another object to make it perform a given process at a given time. Encapsulation property makes such simplicity possible.

Polymorphism was used in software development and originates from it (Armstrong 2006). She also goes on to indicate that the literature appears to inconsistently apply the concept of polymorphism with some likening polymorphism to late binding or dynamic binding (Byard et al, 1990). Bringing together these conceptualizations, Armstrong (2006) defines polymorphism as the ability of different classes to respond to the same message and each implement the method appropriately. In modeling terms, polymorphism as be explained by the use of an example of feeding, which signifies grass to a cow but hunting game for a lion. The same feed process can be used to initiate both processes with the respective classes executing the corresponding processes of their species.

Data abstraction originated in the 1950's and is commonly defined as the property of OOP to simplify complex real life situations by suppressing irrelevant details (Henderson-Sellers 1992, Ledgard 1996, Yourdon 1995).

With the knowledge of OOP also comes the need to know the advantages and disadvantages of it. The object orientation has several ups and downs discussed in detail in the literature (Johnson 2000), but the most important fact about object orientation is the ease of model development. Moreover, the portability, reusability and the extensibility of the code are the most appealing facet of object orientation to the modeling world (Johnson 2000). The ability to apply and use the model developed for one ecosystem and specific conditions and to easily change the model components to adapt to a totally different set of conditions is the ideal scenario for model design and code development.

However, intended users of this model are the ranchers who are responsible for making the decisions and managing the operations of the beef cattle enterprise. This further enhances the requirement for a link between the output of the complex hydrological and nutrient models and the decision making capability of the ranchers. The need is for a decision support tool that processes the data outputted by the models to a form which is easily interpreted by the decision makers. Adding a spatial, geographical information systems module to it would further enhance the authenticity and the confidence of the model, and also improve its ability to accurately model the spatial variance of the landscape.

Decision Support Systems

Hydrologic models have served as a valuable tool for water resources management for many years (Greene and Cruise, 1995). The pressure to develop better and more accurate models requires the ability to better describe the landscape spatially. This can be achieved by the use of geographical information system (GIS) within the model. A loose coupling of the simulation engine and the GIS alone is not sufficient to assist the decision-makers/ stake holders to efficiently make critical decisions. The necessary linkage is provided by the decision support system, which processes the data outputted by the simulation engine and routes it to the GIS module to represent it in a form that would be an effective assistant to a stake-holder. Reitsma (1996) defines a decision support system (DSS) for water resources application as a computer-based system, which integrates state information, dynamic or process information, and plan evaluation tools into a single software implementation. In this definition, state information refers to data that represent the system's state at any point of time, process information represents the first principles governing resource behavior, and evaluation tools refers to software used to transform raw data into information used for decision making (Satti, 2002)

A decision support system extends the scope of the simulation engine of any model to not only include fixed scenarios that are pre-determined and preset, but allows a more complete view of the various possible outcomes and options available to the decision-maker. In other words, it not only looks into what would happen, but also what option could be available to change it. The wide range of applications of DSS techniques for the study of water resources problems includes surface runoff, river basin management, urban storm water management, groundwater contamination, have been discussed in literature (Dunn et al., 1996; Jamieson and Fedra, 1996; Ito et al., 2001; Sample et al., 2001).

The current modeling effort is undertaken using one such decision support system that supports a GIS module and the above section is presented in order to help better understand the use and advantages of a GIS integrated model.

Introduction to Questions and Decisions - QnD

The **Q**uestions a**n**d **D**ecisions (QnD) is a generic environmental modeling system that has been developed using Java based object oriented programming according to Kiker et al. (2006). The ideology behind this simple modeling structure and approach is to present the model as a game (Figure 3-1) which will involve both managers and scientists. The game has appeal to both the communities due to its ability to output data and interpret it according to the need of the user. The managers or decision maker can use the simple user interface to assist them in making management decisions without having to process numerical model output. The model uses several useful and easy to understand methods to appeal to manager using warning light, tabbed pane graphs indicating the trend of several important decision parameters and also a management toolbar that contains management option that can be applied for the next time-step. The user interface is developed using Java swing which provides a major advantage of platform independence.

The model also integrates a geographical information system (GIS) module into the user interface and has the ability to load several layers of shapefile to provide a better understanding of the ecology and the landscape of the region. The GIS module is coupled to the Java model using ‘GeoTools-Lite’, an open source GIS application programmable interface (API) for Java. The GIS module allows the user of the model to do several operations on the spatial units such as select, pan and zoom through a toolbar at the bottom of the screen. This allows the user to select one or more of the pastures and apply some specific management action to those selected pastures/spatial units, which accounts for an interactive and dynamic modeling experience. For the scientists and the number crunchers, the model has also has a more conventional form of output in the form of comma separates value files (.csv) that can be loaded into Microsoft Excel.

An object oriented approach appeals to the world of modeling as the design of object, classes and methods is easier to reflect from their real world equivalents (Kiker et al., 2006). The benefits of an object oriented approach have already been discussed in earlier sections. The elemental objects in programming QnD are Components, Processes and Data (Kiker et al., 2006). In QnD, all of the components are given a ‘C’ prefix, the processes, ‘P’ and the data a ‘D’ prefix. So essentially the building blocks of QnD are the CComponents, PProcesses and the DData. Components are objects of interest (Kiker et al., 2006); a component can be any of the important physical players within the ecosystem, for example fish, grass, forest cover etc. The

Components describe the constituents and entities within a spatial area or spatial unit. Every component has a set of data, sub-components and processes associated with it.

Processes are actions that involve Components, and Data are descriptive objects assigned to components according to Kiker et al. (2006) and Kiker and Linkov (2006), in other words, processes are the tasks that any component performs to interact in some way with both the environment in general and other components. Processes use data to perform operations on the components to show the interaction with other components. The data signifies the properties of the components which are modified by the processes. Figure 2-2 describes a simplistic UML look at the relationship between components, processes and data. The relationship that is shown in the UML can be better described as, processes and data are elements of a component, and a component can have one or more of each of these. A component can also contain sub-components which can have their own processes and data associated with them. The processes too can have sub-processes contained within it. When the QnD: BIR model is discussed in the next chapter, a place of the sub-processes emerge as the major placeholder for all of the calculations. In the UML use case diagrams, Figure 2-3 to Figure 2-6, the role of different actors/players, the coders, model developers and the players, within the QnD system is made clear.

Figure 2-3 describes the role of the coder or the code developer. Coders mainly interact with the Java code in the model. The design, development and maintenance of the model code itself, is the coder’s responsibility. The UML design and overview of the system is also designed and maintained by the coder. A coder can interact with the players, the developers and the outside world overall through the QnD website, with ideas and comments about the model design. The model deployment is the final step of the development. QnD is deployed using Java Network Language Protocol (JNLP) as described in the following sections.

The developer's role is depicted in figure 2-4. The model developer doesn't interact as much with the code itself but primarily with the XML input files. The XML input file provide a powerful and generic way to setup the QnD model, enabling the model developer to apply QnD to different sites without having to change the java code at all. Through the XML the developer can describe the modeled site, the components, processes and data discussed earlier. Moreover, the user interface is also described in the XML by the model developer, all of the warning lights, charts, graphs, GIS images and management options etc are designed and described in the XML by the model developer. The developer interacts with both the players of the system, who are the stakeholders, and the coder to best formulate the model development process. Once the model has been developed, the calibration and validation of the model is the model developer's responsibility.

The players or the users of the model constitute the third class of people who interact with the model. Figure 2-5 describes the interaction of the players to be minimal with the java code or the XML files. They mainly interact with the user interface of the model and the actual output files of the model. Their role as the user is to use the model to better understand the implications of the decisions they are required to make. Players select the scenarios, the management options and essentially run the model.

It is the interaction among these three actors that constitutes the major design and development of the model, by generating a collaborative dialogue amongst the users and the model developers, acquiring technical data and discussing both informal "rules of thumb" and technical implications of management decisions (Kiker et al., 2006). QnD allows both hard data, such as field-measured experiments, and soft data, such as experiential learning or general impressions to be valid model inputs (Kiker et al., 2006). The result of the dialogue is conveyed to the coder in cases where there is a requirement for code changes to the model.

Kiker et al., (2006) describes model development methodology as iterative and interactive, involving alternative discussions with the stakeholders and model development, in order to best understand the requirement of the managers and tailor the model to it. The object oriented nature of the model coupled with the expert knowledge gained from the discussion with the stakeholders provides the backbone of the QnD model.

Once an initial (prototype) version QnD has been developed, it can be used as a game to stimulate further discussions between managers, scientists and stakeholders to try out different management alternatives and investigate possible repercussions of those decisions (Kiker et al, 2006; Kiker and Linkov, 2006).

Once the development of the model is completed and the model has been put through validation, it can be deployed online as a web-based model-game using Java Network Language Protocol. Some of the earlier versions of QnD have been deployed as a game making it a good resource for teaching and learning about the environment.

Overall the object oriented QnD model proves to be a powerful and easy to use decision support tool, which couples an interactive design environment with a quick and efficient model development and deployment cycle. It establishes an essential link between the research oriented, complex hydrologic model and a simplistic user interface driver decision support tool used and preferred by the managers, and hence is ideal for use in the current research study.

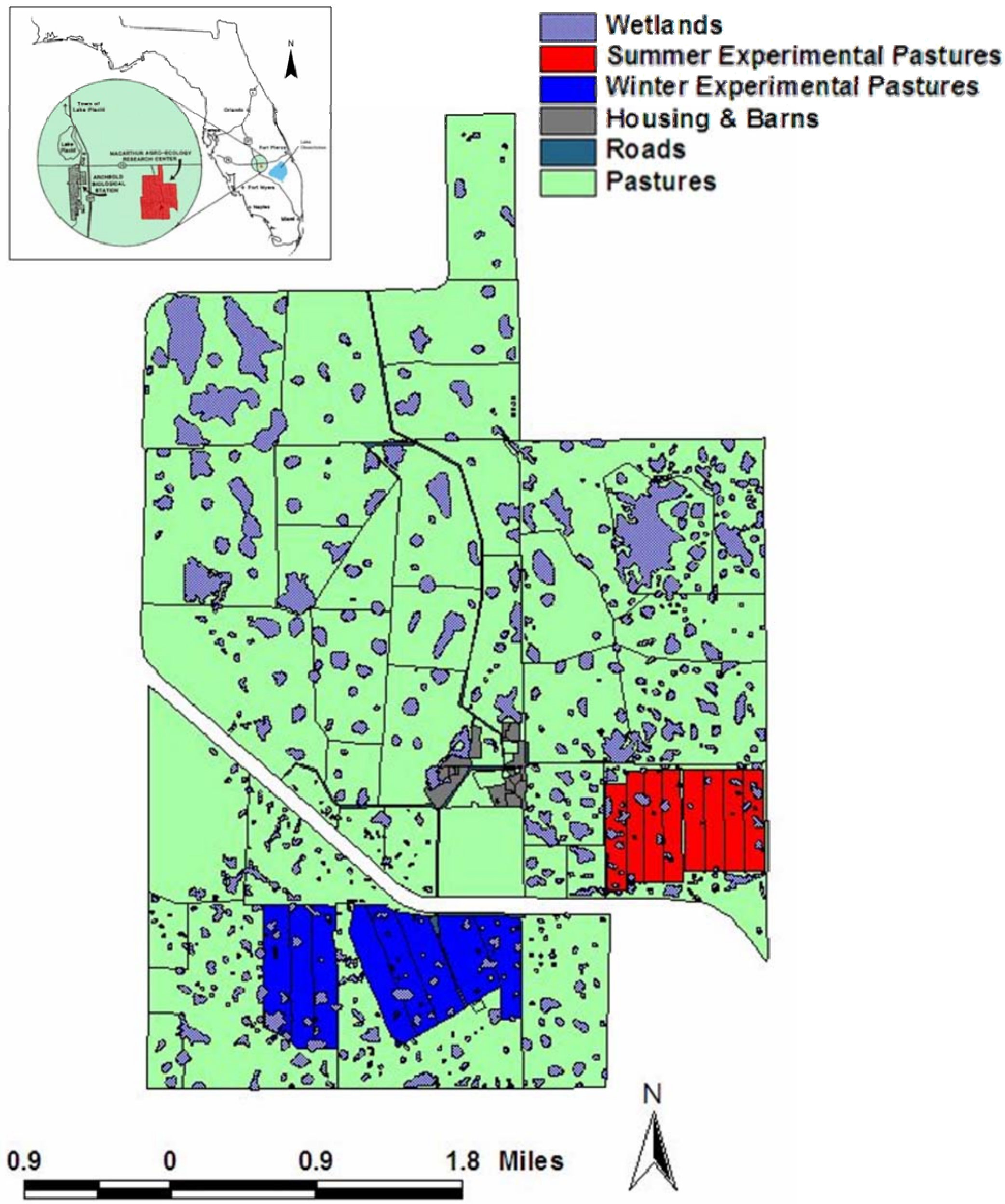


Figure 2-1.The figure shows the Buck Island ranch with its summer and winter experimental pastures. (Kiker et al, 2006)

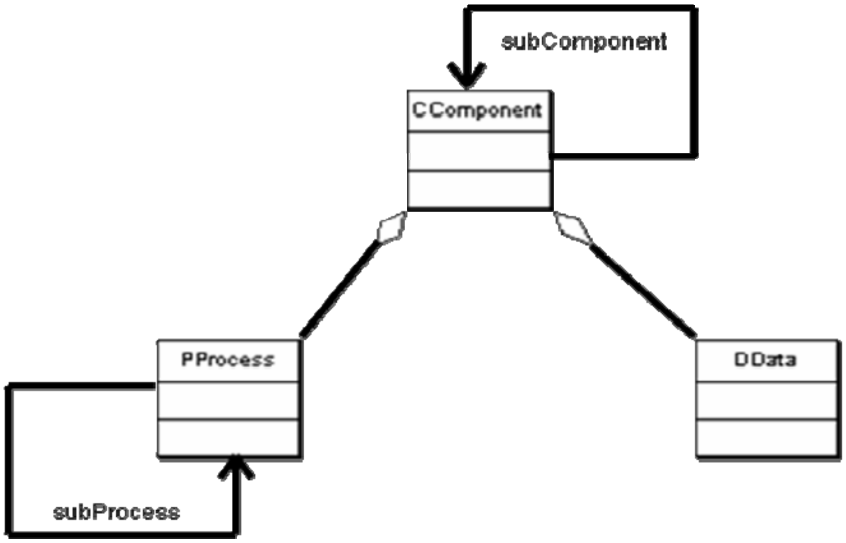


Figure 2-2. A simplistic UML look at the different components of QnD model (Kiker et al. 2006).

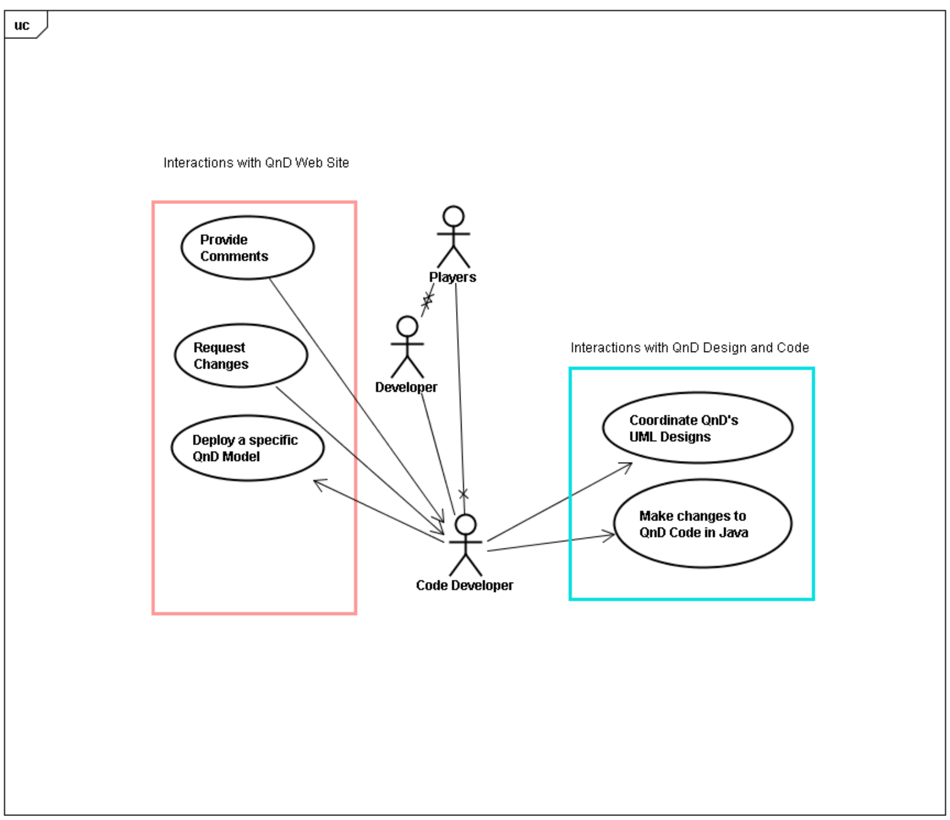


Figure 2-3. Role of the coder or the code developer

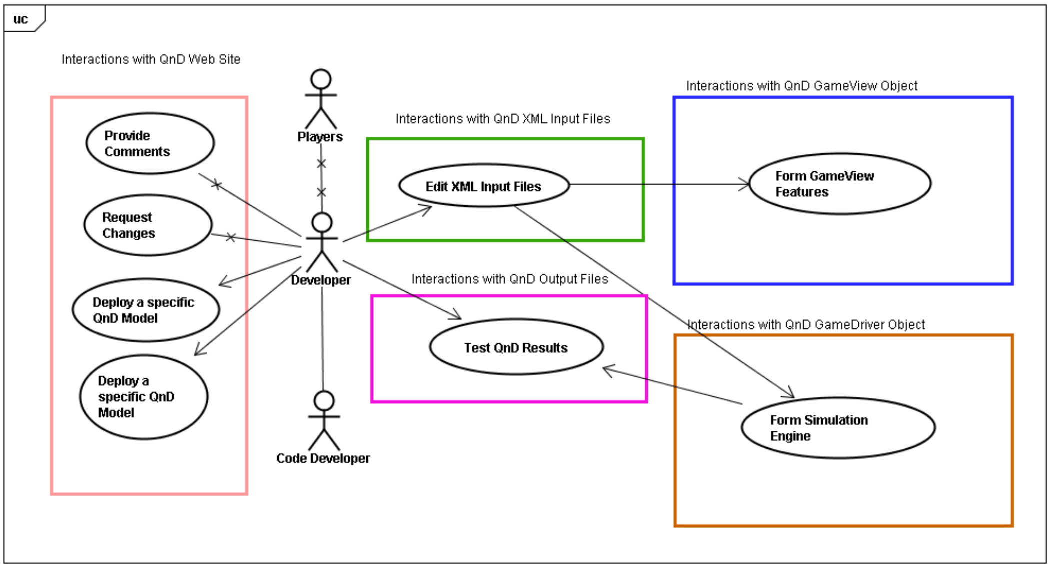


Figure 2-4. The developer's role

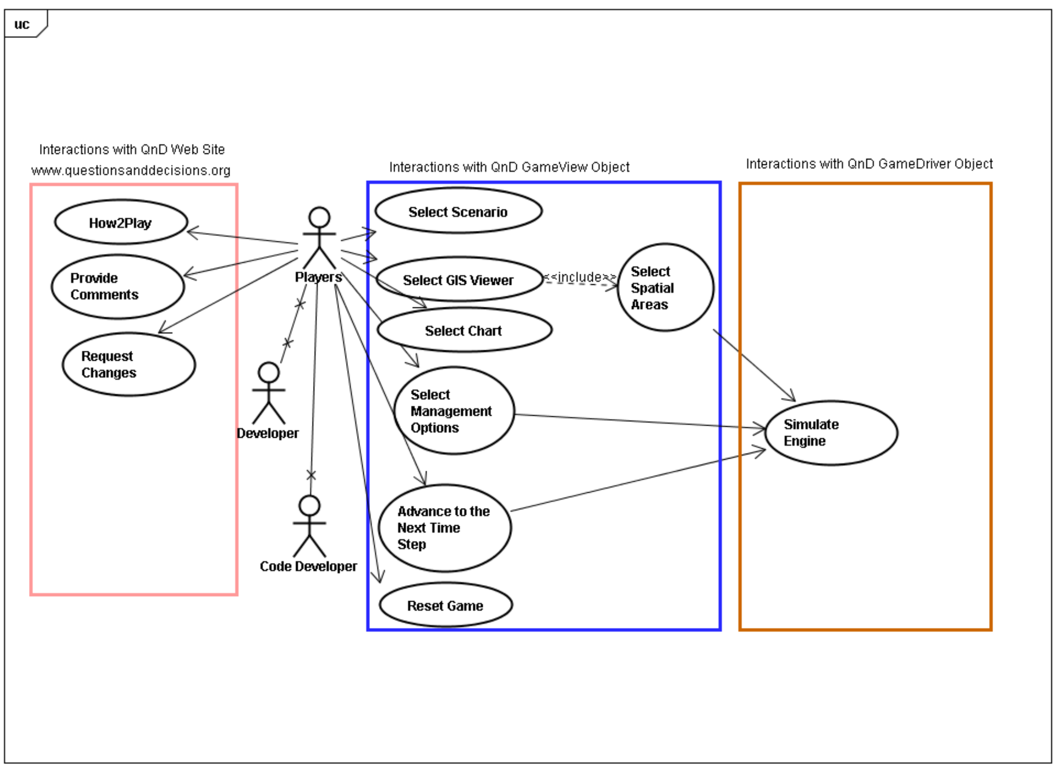


Figure 2-5. The interaction of the players is minimal with the java code or the XML files

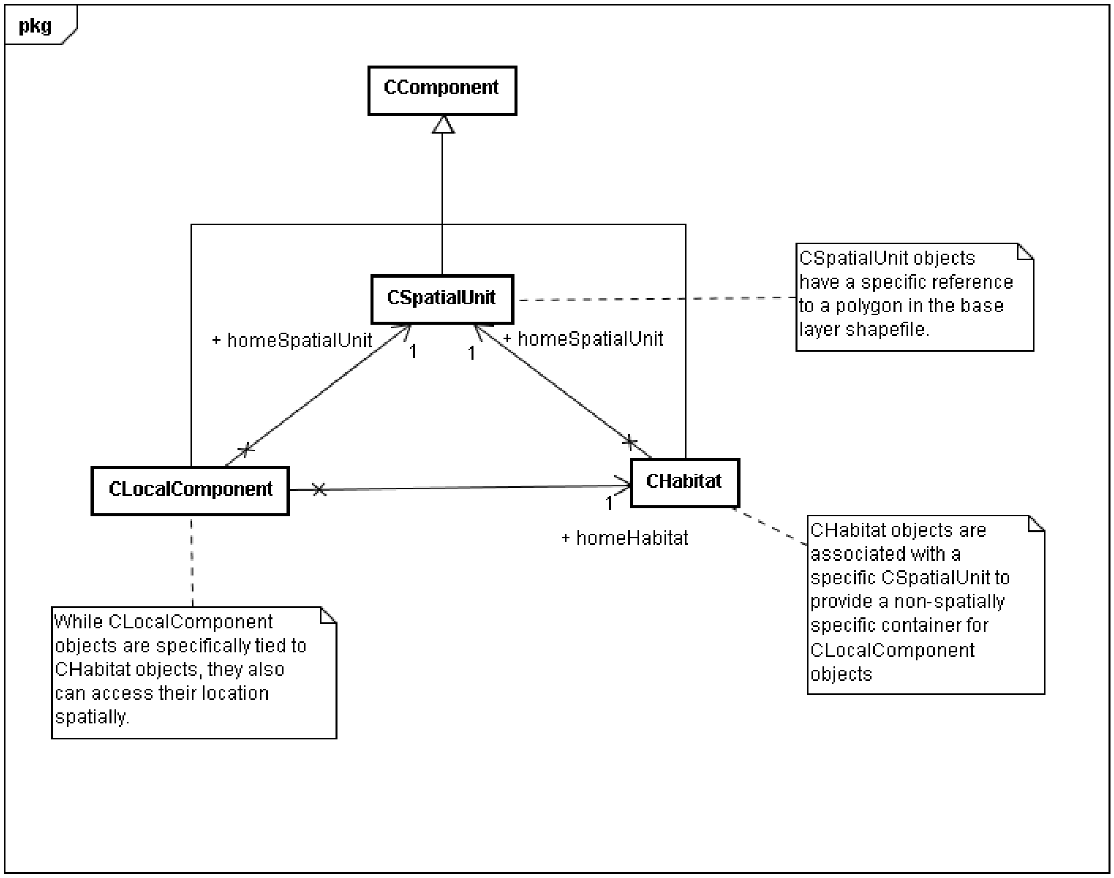


Figure 2-6. The class diagram of a typical QnD system

CHAPTER 3
METHODOLOGY

The objective of this chapter is to provide a detailed account of the current version of the QnD model applied at the Buck Island Ranch (QnD:BIR). The actual design and development of QnD:BIR is discussed, including the major processes involved in the model. Some of the actual objects (components, processes and data) included in the model development are further explored in this chapter, followed by an account of some of the model calibration, validation, error quantization and data representation techniques commonly used.

Design of an Enterprise-Level Model for Buck Island Ranch - QnD:BIR

The modeling effort for the QnD: Buck Island Ranch was designed to be simplistic and based on literature-derived concepts, empirical data and expert knowledge. Most of the relationships in this version of QnD are either empirical, calculated from the data recorded at the research site or is based on the basic laws of hydrology. Figure 3-1 shows a screenshot of the model with the cow icons and the GIS coverage of BIR.

The basic spatial setup of the model divides the whole area of BIR into 68 spatial units (CSpatialUnit), each representing the 68 pastures on the ranch. Each of these spatial units contain a CHabitat, which the main holder of the other local components. In QnD:BIR, the habitat is considered to be ‘default’ and is contained in all spatial units. Each of the CHabitats contains several local components including CBahiagrass, CNativegrass, CUplandSoil, CWetlandSoil, and a CHerd wherever a herd is present. This is further clarified with the help of the UML class diagram in Figure 3-2. The grasses and soil have a percent area DData, which signifies whether the selected spatial unit is an upland or a wetland, improved or native pasture. Moreover, another DData (DImprovedPasture) property is defined to signify whether the current spatial unit is an improved or a native pasture. There are several other DData objects and processes which are global to the model which signify values used for calculation (DZero etc) or are input/output variables of the model.

The main focus of this model is to simulate five major aspects of the Buck Island ranch ecosystem and ranch management operations:

QnD:BIR - Hydrology

The hydrology of this region has been previously modeled by in-depth models like ACRU2000 (Campbell et al., 2001; Clark et al., 2001; Kiker and Clark, 2001; Martinez, 2006; Yang, 2006; Pandey, 2007) and WAM (SWET, 2002), which have enabled highly detailed sub-daily modeling. On the other hand, the QnD Buck Island Ranch model has followed a very simplistic, deterministic method to model the hydrology of this region by using simple relationships between the Ground Water level data and the amount of available storage in the soil. This enables the development of an effective hydrological model in a short period of time which models the actual data on a monthly scale within acceptable levels of accuracy.

The model structure is defined by a number of equations and relationships. One of the major inputs for modeling the hydrology of any region is the rainfall data. For the QnD Buck Island Ranch model, the Average monthly rainfall data is provided as input to the model. This model uses Ground Water Level as an input factor for calculating the runoff. Ground water table data is read in as input to the model. The height of the possible available column of storage is calculated as the difference between the mean height of Buck Island Ranch from the sea level and the height of the ground water table. i.e.

Possible Available Column of Storage (in meters) = Mean Height of Buck Island Ranch (in meters above Sea Level) – Mean Height of Ground Water Table (in meters above Sea Level) (3-1)

The available water storage is dependent on the soil type. This value, deduced from the Possible Available Column of Storage, is based on the porosity and the field capacity of the soil. This factor accounts for the plant available storage and the gravitational storage i.e.

Available Water Storage (in mm) = Possible Available Column of Storage (in mm) * (Porosity – Field Capacity) (3-2)

Moreover, an evapotranspiration (ET) factor is also added to this plant available storage which is calculate as a function of average temperature of the area during the month. There are other factors that affect ET, but since temperature is the major factor, it is taken into account in the model.

The value of the possible runoff is calculated as the difference between the rainfall and the actual available storage.

Runoff (mm) = Total monthly rainfall(in mm) – (Available Water Storage (mm) * ET factor) (3-3)

Finally, the total runoff volume is calculated for each pasture, taking into effect its area and the amount of runoff as a result of rainfall, i.e., the total runoff volume is calculated for every pasture using the equation:

Runoff Volume (in L) = Area of the Pasture (square m) * Runoff (mm) (3-4)

To visualize the model using the object oriented approach used by QnD, each of the values being calculated represents a DData, and each relationship/equation is described by one or more PProcesses. The hydrology component is governed by the soil component (CUplandSoil or CWetlandSoil), which contains the PProcesses. The inputs are again DData values which are either local to the spatial unit (DPercentAvailableStorage) or globally exist (DMonthlyRainfall). In QnD terminology, the whole of hydrology is large a part of a single PProcess, PCalculateRunoff, that governs it. This PProcess has includes several sub-processes which perform the calculations based on the relationships described earlier. The detailed list of processes supported by QnD and their explanations are part of appendix B. These sub-processes systematically perform the calculations in the order they were setup, and the calculated results of total runoff volume is stored in the DData, DRunoffVolume. It is important to note that QnD only performs the processes at every time-step, if the component is present in specific spatial unit that is being updated.

QnD:BIR - Nutrients

The nutrient movement of this region has been previously modeled by in-depth models like ACRU2000 (Campbell et al., 2001; Clark et al., 2001; Kiker and Clark, 2001) and WAM (SWET, 2002) which have enabled highly-detailed modeling. On the other hand, the QnD Buck Island Ranch model has followed a very simplistic, deterministic method to model the nutrients of this region by using simple relationships. The simplistic approach enables the modeling of the complete ranch, on a broad scale, which helps to better understand ranch dynamics and the effect of the hydrology and nutrient cycle on ranch management and profitability. In this model, nutrients in the region are divided into extractible phosphorus and stable phosphorus as perceived from the standpoint of the model. The extractible phosphorus is responsible for all the nutrient movement from the soil to the cows and in the hydrology. The stable phosphorus, as the name suggests, is considered to be relatively stable and is always present in the soil. However, every time step, there is a nutrient movement from the extractible phosphorus to the stable phosphorus and vice versa at different rates. This movement is governed by transfer coefficients that are used to transfer extractible to stable phosphorus and vice versa. This process of transfer can be shown by a series of equations as following:

Extractible to Stable Phosphorus Transfer Amount (in kg) = Extractible to Stable Transfer Coefficient * Extractible Phosphorus (in kg). (3-5)

Stable to Extractible Phosphorus Transfer Amount (in kg) = Stable to Extractible Transfer Coefficient * Stable Phosphorus (in kg). (3-6)

The runoff event triggers the movement of a fraction of the Extractible Phosphorus with the runoff. This amount of phosphorus or in other words, the runoff phosphorus load (measured in kilograms) is calculated in the model using an empirical linear relationship that is derived directly from the measured BIR data.

This linear relationship is based upon the measured average runoff volume to the measured average phosphorus load for the set of native and improved pastures. Figure 3-3 shows the trend line characteristic of this linear relationship.

The object oriented interpretation of these conditions and components, which is used by QnD, describes the pools of phosphorus as a property of the soil component (CUplandSoil or CWetlandSoil) of the spatial unit. Each of these components contains DData values which signify the presence and amount of extractable (DExtractableP) and stable (DStableP). PProcesses, PExtractableToStableTransfer and PStableToExtractableTransfer interpret the phosphorus transfer between the two pools, using the PTransfer process type, to the object oriented QnD model, incorporating the equations discussed earlier in the section.

The actual phosphorus load coming off of the spatial unit is governed by the PExportInRunoffImproved and PExportInRunoffNative processes which correspond to the Runoff vs. PLoad relationships described earlier for the improved and native pastures respectively. Both of these processes affect the total phosphorus load DData (DPLoad), updating its value at every timestep.

QnD:BIR – Forage Growth

The forage model component of QnD:BIR is again designed with the similar simplistic approach as the other components of QnD. Forage is a very important component of the BIR ecosystem and the sustenance of the ranch depends on the cows having enough forage to feed on. Lack of forage growth also causes the cow/ calf condition to worsen and thereby result in unhealthy cows and additional expenditure in buying supplemental feed for the cow. QnD:BIR mainly considers there are two factors that affect the growth of forage, the relative rainfall and the seasonal effect.

For the effect of relative rainfall, the average monthly rainfall for the whole period is calculated for every month.

$$\text{Average monthly rainfall}_{(\text{month} = \text{'Jan'})}\ (\text{mm}) = \Sigma_{(\text{All years})}\ \text{Monthly rainfall (mm)} / N \quad (3\text{-}7)$$

The average monthly rainfall is then used by the model to calculate the relative rainfall for the current month.

The relative monthly rainfall affects the forage growth as an empirical linear relationship. The values of this relationship are calibrated to best suit the conditions present at BIR, with within the confines of the acceptable results.

Forage growth rate = f (relative monthly rainfall) (using the linear relationship). (3-8)

Total grass biomass (Total Forage) = Forage growth rate * Total grass biomass (3-9)

The seasonal effect on forage is more complex within the model than rainfall effect. Moreover, it also accounts for the wilting of the grass during dry season. This is governed by an empirical curve, which is calibrated to suit the site being modeled i.e. the Buck Island ranch. The seasonal effect is governed by similar equations as mentioned above:

Forage growth rate = f (current month) (using the curve). (3-10)

Total grass biomass (Total Forage) (in 1000 kg) = Forage growth rate * Total grass biomass (in 1000 kg) (3-11)

Similar relations are used to model both native and improved pastures, where the herds are present and the herds consume the grass at a constant rate per day per cow. The specific value and its background are mentioned the next few subsections. With the coupling of the three factors, QnD:BIR overall presents a good and simplistic model design based off of expert opinion, literature and the ranchers view of their ecosystem.

Forage growth relations are incorporated into the model using two simple PRelationship sub-processes within the PCalculateForageGrowth process. These two PRelationships signify the rainfall effect and the seasonal effect on forage, defined earlier in this section. The forage relationships are specified within the CBahiaGrass or the CNativeGrass components of the model, which are to the most part similar.

QnD:BIR - Beef Cattle Management

The cows are the most integral part of the Buck Island Ranch ecosystem. As mentioned earlier, the ranch is primarily a beef cattle ranch and cows are a major asset and a very important player in the ecological balance at the ranch. The model is primarily a management tool, with its primary focus as the stakeholders and their interests, which, in this case, are the ranchers at the Buck Island Ranch. Figure 3-4 shows a timeline for the ranch management operations, the model is primarily based on these timelines to effectively simulate the beef cattle enterprise.

The modeling of the cows at the Buck Island Ranch has been developed based upon the figure shown above. The model portrays three aspects of the life cycle of the calves, i) the impregnation of the cows (breeding), ii) the birth of the calves, and iii) the time when the calves are weaned and sold.

Breeding

The calves born on the ranch that can be further divided into three categories on the basis of the part of the breeding season that the cows are impregnated in, namely: the calves born of cows that are impregnated early in the season, which form the early cohort; the calves born of cows that are impregnated in the middle of the season, which form the middle cohort; and the calves born of cows that are impregnated late in the season, which form the late cohort. This breeding season ranges from January to the end of April. The rate of impregnation during this season depends upon the climatic conditions, i.e., temperature, rainfall, etc. and the condition of the cow. From the analysis of the ranch Standardized Performance Analysis (SPA) data, the average impregnation rate of the cows all through the breeding season in the ranch is between 75% and 80%. The model assumes an almost equal rate of impregnation throughout the breeding season, only varying due to the climatic conditions. During the entirety of the breeding season, all the herds of cows on the ranch are exposed to bulls for a time period ranging from 90-120 days, and the ratio of the number of bulls to cows is 1:25 (Source: Patrick Bolen).

Calving

The average gestation period of the cows is 9 months (Source: Patrick Bolen), hence the first calves are born around November from the cows that were impregnated early in the breeding season. The calving continues all the way through to the end of the following February. The cows impregnated early in the breeding season give birth at the onset of the calving periods, around the month of November, and the calves so born form the early cohort. Similarly, the middle- and the Late Cohorts are born all the way through February. The population of the cohorts can be calculated by the following equations:

Early Cohort Population (cow units) = Early Pregnancy Rate * Cow Population (3-12)

Middle Cohort Population (cow units) = Middle Pregnancy Rate * Cow Population (3-13)

Late Cohort Population (cow units) = Late Pregnancy Rate * Cow Population (3-14)

The pregnancy rates for early, middle and late cohorts are dependent on the condition of the cow.

Weaning and selling

From the time of birth, the calves gain 1.4 pounds a day, on an average (Kunkle et al., 2001). The calves are weaned around the month of May. At this stage, it is ensured that the calves reach their endured target-selling weight of about 492 pounds on an average.(SPA 2005) The calves that fall short of the required mark could be fattened by using one or more techniques such as supplemental feed or/ hormones. This is reflected in the model as a management decision that the user can make while running the model. Once this is done, the calves are sold in cohorts. The selling of the calves is also a management decision which is part of the user interface in the model. This gives the user/stakeholder the option to sell any/all cohorts at the time he thinks is right for the ranch.

Cow intake and waste

Intake

The average intake per day per cow is about 25.9 pounds of dry matter (Kunkle, 2002). Of all the food ingested by the cattle, the utilization rate is about 55%, i.e. the nutrition level of the food ingested by the cattle (Kunkle 2002). This utilization rate is higher for Bahiagrass as compared to the other varieties of forage (Kunkle 2002). This percentage of utilization of the forage by the cows is calculated from the amount of grass/forage available on the pasture. After the forage is ingested by the cattle, the total grass biomass is also calculated and updated.

Waste

The cattle waste on the ranch is modeled primarily for the phosphorus and nitrogen content present in it. The amount of phosphorus present in the cattle waste is about 0.044 kg/cow and about 0.04 kg/calf and the amount of nitrogen is about 0.019 kg/cow and 0.017 kg/ calf (ASABE Standards 2007). Of the total amount of phosphorus and nitrogen present in the cattle waste, a certain percentage is extractible. This value of extractible phosphorus and nitrogen is accordingly updated from the phosphorus and nitrogen loads that are dropped on the soil.

The beef cattle management is more complex to visualize in object oriented terms due to the variety of factors, parameters and processes involved. To start with, the cattle herd can be looked at as a component (object) and all of the QnD:BIR beef cattle management is contained within this local component. Several PProcesses are included within this component each signifying the various major aspect of ranch management discussed earlier in this section (breeding, calving and selling).

It is important to note that, each of these beef cattle management sections are implemented for each of the three cohorts that the calves are divided into. This further complicated the design of the QnD:BIR beef cattle management. An attempt has been made to retain the simplicity of the design of the XMLs to assist any of the stakeholders, who might be interested in the design of the model, to understand it easily.

QnD:BIR - Ranch Incomes and Expenditures

Consideration of the financial details in the model starts with the previous year's ending balance as the current year's beginning balance. This amount is considered to be a fixed value for the purpose of this model. During the course of the management cycle, the ranch may incur a variety of both revenue as well as expenses. The major source of revenue for the ranch is the sale of the calves, which are sold at an average price of about $1.10/pound of calf (Source: Standardized Performance Analysis, MAERC). Other sources of revenue may include SOD and sale of pregnant cows or bulls. In our model, we look mainly at the sale of cows and the lifting of SOD, both of which are management options available to the user. At the end of each monthly time step, we calculate the total revenue gained by the ranch.

The ranch also incurs a number of management and maintenance expenses that include feeding and grooming of the cattle. One of the major expenses of the ranch is providing supplementary feed during the preconditioning period of the calves. To improve the total yearly yield, the ranch also buys impregnated cows. Another source of expenditure at the ranch is the hormones injected into the cows, which is an almost regular practise (Source: Patrick Bolen). Apart from the abovementioned expenses, there are a number of other conditional expenses that may be incurred by the ranch, one of which includes pumping water. During the years that the ground water level is low, additional water is pumped into the canal and may cause electricity overhead.

To analyze the various combinations of conditions and their corresponding financial repercussions, the model is designed with the idea that the user of the tool, i.e., the rancher, gains an overall management and financial perspective and can vary the conditions to study the effects. This takes into consideration that within the model, all these options are mainly management options which the user can set while he is running the model, the idea being that the financial decisions should always remain in control of the rancher who is using the tool.

The object oriented model interpretation of incomes and expenditures has far-reaching applications, outside the field of hydrological and ranch operation modeling. QnD:BIR establishes a link, on a simplistic level, between the world of economics and the object oriented programming model. The model design handles the ranch's month to month economics by tracking on a simplistic level, the incomes and expenditure of the ranch through the cow/calf operation. The two DData values of DTotalIncome and DTotalExpenses govern these two values. And the different between them is considered to be the operating balance of the ranch (DTotalOperatingAmount). The incomes and expenses are usually a result of the management options which the PTotalExpenses and PTotalIncome aggregate to update the values of DTotalIncome and DTotalExpenses. Incomes and expenditures can be a result of more than just cow/calf operations, for example, pumping excess water etc. can also result in the ranch incurring expenses. Hence this module of QnD:BIR is controlled at the global level, and does not belong to any local component. However, as each of the local components contribute to the total incomes and expenditures, the values are updated and the total operating amount is calculated at the end of every timestep.

Overall, this module can be looked at as a set of processes or operations in the object oriented sense, which is affect by individual objects or components through their respective local processes. A similar simplistic design can be a starting point for the development of other applications that need to translate financial or economic processes into object oriented programming.

Addition of New Features into the QnD Model

Initial design and versions of QnD:BIR were reviewed by ranch management and scientists who requested that a significant new feature would need to be added to the user interface; moveable icons that represent cattle herds. The requested features were not present in any of the previous models of QnD. Thus, an additional feature in QnD Buck Island Ranch is the capability to add icons representing cows on the spatial units representing pastures. These icons can be placed on the spatial units if the data suggests the presence of a cow herd on the corresponding pasture. The cow icons can be moved as one moves the cows from one pasture to another as part of a management decision. This capability to move cow herds is a very important part of the management cycle of the operation on the ranch.

The technological challenge associated with the development of such a management option and dynamic icon movement is what makes in a special feature of QnD:BIR. The dynamic placement of the cow icons on the pastures to indicate the presence of a herd involves placing an additional GIS layer, a marker point layer, on top of the existing GIS maps that are loaded at startup. The GeoTools-Lite is generally a useful API for GIS, but the documentation of it is still sparse which further complicates the task. This point layer is generates by checking each of the spatial units that are being loaded from the XML files for the presence of a herd or in QnD terms the presence of a CHerd component. If a CHerd is found in a spatial unit (CSpatialUnit), a new point is added at the (x, y) location of the centroid on the new marker layer. The procedure is replicated for all of the spatial units and the result is the placement of the cow icons on the user interface GIS map of QnD:BIR.

Once the icons are placed onto the GIS map, moving the cows as a management option is the next technical difficulty. QnD supports the movement of a component from one spatial unit to another, wherein, all of the processes and data linkages are moved along with the component to the destination spatial unit and the links are reestablished. In order to facilitate the management option of moving cows, Java Swing objects were used to create the user interface extensions and QnD component movement support was used to move the cows in the model setup. When the cows are moved, instead of having to redraw the whole marker layer, QnD:BIR simply loads the marker layer and deleted that one point corresponding to the CHerd being moved and adds a new point at the destination spatial unit. The map is then refreshed in order to reflect the changes made to the layers.

This management option provides future model developers, the option to move their components during the course of a model run as a part of a management decision, which in turn further expands the flexibility of the model itself.

The simplistic model design of QnD:BIR enables it to cover varied modules, on a ranch scale. Moreover, the design also accommodates any future improvements to the model structure and design relationships, hence making it highly extendable.

Model Calibration, Validation and Data Representation

The efficient development and working of a model requires checking the accuracy of the results and increasing the robustness of the model. Model Testing is used to improve the performance of the model by detecting the design shortcomings in the model algorithms and using procedures like calibration and validation to improve the hardiness of the model as well as its accuracy and performance. The following sections expand on the procedures used for model calibration and validation:

Model Calibration

Model calibration is the methodology used to tune or update the model settings to suit the site that it is being used for. Model calibration process involves identifying parameters that within the model, that could allow the possibility of an error factor, namely parameters that have been used from a general national average or derived from other studies at different sites where the conditions might not be exactly the same as the chosen research site. Once these parameters have been identified, their values are changed to suit the conditions being modeled. Moreover, for the calibration period chosen, these parameters values are corrected within the allowable limits to best capture/follow the observed data trends.

Model calibration is done in order to improve the model's accuracy, by adjusting the parameters to best suit the historical data observed. However, the more complex the model, the more parameters that can be changed, making the calibration process to be more and more complex.

Model Validation

Model calibration prepares the model to best suit the conditions at the current research site. A model is then validated by running it for the validation period without any further change in parameters or setup after it has been calibrated. The results of these runs are then compared to the observed/measures values of the parameters that are being modeled. This is done in order to gauge the effectiveness of the model and its setup. During the validation period, several statistical and other methods are used to calculate and quantify the error that is present in the model. The following sections describe some of the commonly used statistical error quantification methods.

Model Evaluation

Graphical representation of the model results does quantify the model and the general trend between the observed and the model results. However, visual evaluation of the results alone is not sufficient to gauge the effectiveness and accuracy of the model. Statistical analysis methods are used to quantify the visual evaluation of the result by using several methodologies to quantify the amount of error that is exhibited by the model results. The following section attempts to give an overview of a few commonly used model evaluation techniques.

Statistical Representation

Quantitative methodologies of analysis are required to evaluate the results of a calibrated model. This section looks at some of the commonly used methodologies that are used to validate the results of this modeling effort, namely, Root Mean Square Error (RMSE), Pearson product-moment correlation coefficient (R^2), and Nash-Sutcliffe (NS) Coefficient (Nash and Sutcliffe, 1970). In all the following equations, P_i is the observed value, O_i is the model-simulated value, and N is the number of observations.

The Root Mean Square Error: RMSE is essentially the overall sum of squares errors normalized to the number of observations (Hession et al., 1994)(Yang 2006). The RMSE is calculated in the same units as the analyzing quantity. The following equation is used to calculate the RMSE:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2} \qquad 0 \le RMSE \le +\infty \qquad (3\text{-}15)$$

This value can be interpreted in term of the units of the modeled parameter. Due to the presence of a quadratic term in the equation, a large error value has a greater effect and on the other end, smaller values indicate better model performance (Evans et al., 2003)

Pearson product-moment correlation coefficient (R^2), is the measure of linearity between two variables. R^2 is probably the most popular measure of fit in statistical modeling. The values of R^2 can range between 0 and 1, with 1 being the 'perfect' match of measured and predicted. The equation used to calculate the value of the coefficient (R^2) is given by:

$$R^2 = \left[\frac{\sum_{i=1}^{N}(O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum(O_i - \overline{O})^2}\sqrt{\sum(P_i - \overline{P})^2}}\right]^2 \qquad 0 \le R^2 \le 1 \qquad (3\text{-}16)$$

The Nash-Sutcliffe (NS) coefficient (Nash and Sutcliffe, 1970) is one of the more effective ways to indicate a goodness of fit. This method is also recommended by the American Society of Civil Engineers (ASCE, 1993) as an effective instrument of model validation. An NS value of 1 indicates a perfect fit and alternately, as the value approaches zero, the lesser the accuracy of prediction of the model. The NS can be computed by using the following:

$$NS = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - \overline{O})^2} \qquad -\infty < NS \leq 1 \tag{3-17}$$

The NS is most effective when the coefficient of variation for the observed data set is large (ASCE, 1993).

The modified form of C_{eff} was developed by Krause et al. (2005) to reduce the sensitivity of C_{eff} to large values:

$$C_{eff\_m} = 1 - \frac{\sum_{i=1}^{N}\left(O_i - P_i\right)^j}{\sum_{i=1}^{N}\left(O_i - \overline{O}\right)^j} \text{ with } j=1 \tag{3-18}$$

The overall model design is simplistic but the knowledge based iterative approach strengthens the modeling effort. The strength of the model is measures through the process of testing and validating the model, which is described in the following chapter.

CHAPTER 4
MODEL TESTING, RESULTS AND DISCUSSION

This chapter focuses on the results and the testing of the model. Model results from the calibration to the validation stage are represented using a variety of graphical methods and an analysis of the most and least favorable results is performed to indentify the strengths and weaknesses of the model.

The QnD:BIR decision support tool, as discussed in Chapter 3, is developed using Java and object orientation for the south Florida beef cattle agro-ecosystem. This model uses simple relationships based on measured data, the laws of hydrology and results derived from consultation with the ranch managers. The model was developed to be applied on a whole farm for a variety of processes and events being modeled, ranging from hydrology and nutrient movement, which is the major validation modules of the model, to cow/ranch management and the income-expenditure cycle. The enterprise management and the income-expenditure cycle run different scenarios to assist the decision makers to interpret the output of the hydrology and nutrient engine and its effect on enterprise management and profitability. The time-step for the version 1.0 of QnD Buck Island Ranch is set to be monthly to better suit it to the decision timescale at which the ranch is being managed.

Model Inputs

QnD is capable of reading time series inputs from a file in comma-separated format. These files have to be declared in the XML input files of the model which are read in and stored in hash tables. For QnD: Buck Island Ranch, the inputs provided to the model include average monthly rainfall and ground water table depth, which are being read from time series files. For the GIS module, a GIS shapefile describing the modeled area is also a part of the input, which contains the area and perimeter of each pasture, which is also read in as input. All of the input that is read is stored into *DDriverData* objects.

As a part of the discussion about the inputs of the model, an overview of the input data and its implications is warranted. Figure 4-1 is a graph of the total monthly rainfall and the ground water levels of BIR. From the graph we notice that the time period that we are applying the model is a combination of wet and dry periods. Early 2000 and 2001 were relatively dry periods, with low ground water table. June – September 2001 is a wet period with high rainfall and as a result we notice a rise in the water table depth. This is again followed by a relatively dry period between October 2001 and June 2002. Hence the water table too drops slowly. The point to be noted here is that the water table is supported to some extent by the presence of the Harney-Pond canal which is maintained at an almost constant height, and which contributes to the water table. But this effect of the canal is already considered by the model by taking the water table depths directly as input.

The following year, late 2002 - 2003 is a wet year with rainfall events sparred throughout the year. This results in the water table staying relatively high throughout this period, which presents two different scenarios. Firstly, late 2002 period, wherein, the rainfall is relatively low, but the level of the water table does not drop, in fact there is a slight increase observed during this period. Alternatively, the period of mid to late 2003 presents a different scenario of high water table and large amount of rainfall. Each of these scenarios could affect the accuracy of the model, as QnD:BIR directly relates rainfall and ground water depth with runoff. This implies that a high water table would result in even a slight amount of rainfall causing heavy runoff, which might lead the model to over-predict in this period.

This overview is designed to understand the input conditions that the model is being tested upon and their implications and effects on the model.

Model Outputs

QnD outputs data in two modes, one of them is through the graphical user interface (GUI) which would be graphs and indicator lights mainly intended for the decision makers to assist them in managing the enterprise. These outputs can be customized to suit the requirement of the enterprise being managed. For QnD: BIR, GUI outputs are the cow and calf population and the operating-amount remaining. The other, more conventional, mode of output is the comma separated file (.csv) with the numerical values of the output parameters. For QnD: BIR, runoff volume, phosphorus load and grass biomass constitute the major outputs required for validation of the model.

Model Calibration

The model was calibrated for the dry period of September 2000- January 2001 and a wet period of July 2001 and August 2001, for the experimental pastures summer pastures 1-8 and winter pastures 1-8. For the hydrological model, the parameter used for calibrating the model is the percent available storage, which combines the effect of plant available storage and the gravitational storage. Within the forage model, the rainfall effect and seasonal effect parameters are the parameters that the model was calibration on.

Hydrology

During calibration, the hydrology of the model was calibrated based on the percent available storage parameter. The calibrated value of this parameter was determined to be 0.238. This number is large enough to account for the plant available storage and in also the effect of evapotranspiration on the rainfall, which is not taken into consideration by the model separately. The model overall was predicting the runoff amounts on the higher than the measured values.

Figure 4-2 shows a typical graph for one of the summer and one of the winter pastures during calibration. This covers the trend shown in more detail in appendix A, which contains all the results from all of the experimental pastures. Since part of the calibration period is one of the driest times for the region, the model calibration should have helped it predict any future dry patches with accuracy.

Nutrients

Calibration period model runs for nutrients followed a similar trend at the hydrology, with the measured values being less than the model predicted. Figure 4-3 shows a typical graph for one of the summer and one of the winter pastures during calibration. This covers the trend shown in more detail in appendix A, which contains all the results from all of the experimental pastures.

Forage

The forage model calibration was done for the period of 2000-2001. The Buck Island ranch forage data set does provide forage yield data for January, March, and December of 2000. Moreover, the forage yield for the each pasture varies over a range for any given month. QnD:BIR was calibrated within the range of values measured at BIR. Hence, the model calibrated for the available ranges, in the absence of continuous data, for the calibration period.

Model Validation/Testing

Model testing for remaining time series data is described in this section. In order to give a general idea of the trends of the model over the sixteen pastures, the highest and lowest performance levels of the model for both the improved (summer) and native (winter) pastures. Additional results are provided in appendix A.

Hydrology

Considering the overall predictions of the model, it can be seen that the overall model tends to marginally overpredict the values of runoff, given the scale of the values, while missing some of the smaller runoff events. Analysis of Summer 5 (Figure 4-2) Pasture indicated that the model predicted the values quite closely with a Nash-Sutcliffe coefficient (NS-Ceff) of 0.6169, a Root Mean Square Error (RMSE) of approximately 5.025 million liters, and a Normalized Mean Square Error (nMSE) of 0.3831. During the validation period between January 2001 and December 2003 excluding the calibration months, the higher peak events occurred during the months of May and September of 2001, 2002 and 2003, and January of 2003 of which the model predicted most months with an acceptable degree of accuracy except those of September 2000, October 2001, June 2002, and January 2003 where it missed some of the more significant events. However, some of the smaller runoff events occurring during the early months of the year each year were missed by the model.

The cumulative Runoffs, however, are generally close to the measured values, indicating that the overall amount of runoff from the Summer 5 pasture (Figure 4-3) is being predicted with better levels of accuracy. This indicates that though the model misses a few small events, it is able to predict the total volume of runoff over a period of time. In the graph of the cumulative runoffs, the curve of the measured values follows the curve of the predicted values very closely, which, along with the high Nash-Sutcliffe coefficient value, makes Summer 5 the best performance of the model for summer pastures.

On analyzing the measured vs predicted scatter graphs (Figure 4-4), it can be seen that Summer 5 has one of the best prediction trend among all the summer pastures for runoffs. The overall model does tend to marginally under-predict the values; however, the error value is not very high. The measured values and the predicted values are also highly proportional.

Considering the least favorable of the model’s performances, analysis of the Summer 4 pasture (Figure 4-5) indicated that the model did not perform as well. The graph indicates a greater degree of over-prediction than other pastures with a NS-Ceff value of 0.5100, an nMSE of 0.4900 and a RMSE of approximately 4.113 million liters. During the validation period between January 2001 and December 2003, the model predicted the higher peaks that occurred during the months of May and September of 2001, 2002 and 2003, and January of 2003, with a lesser degree of accuracy than the best performance of the model. Moreover, the model missed predicting a few of the events that occurred during the months of September 2000, October 2001, December, January and February 2003.

The predicted cumulative runoffs for this pasture (Figure 4-6) are higher than the model measured cumulative runoff values. The values begin together at the start of the validation period, but move apart from September 2001, when the model missed a runoff event. Following this period, the distance between the two curves increases since the model overpredicts the peaks in 2002, except for certain points where they come marginally closer.

The measured vs predicted scatter graphs (Figure 4-7) for Summer 4 indicates that a percentage of the values are over-predicted. The NS-Ceff value is also calculated to be the minimum among the coefficient values of all the other summer pastures, which indicates that the model has not proven as effective in modeling Summer 4.

Though the overall values were less accurate than the model's best performance, the model still managed to capture the general trend of the peaks and the lows of the predicted values quite accurately.

Moving to the native pastures, among all the model predictions for the native or winter pastures, the best performance of the model is shown in Winter 4 (W4) (Figure 4-8), with a NS-Ceff of 0.809, which is considered to be quite accurate, an nMSE of 0.1908, and an RMSE of approximately 5.608 million liters. The runoff graph for W4 shows a close match between the measured values and the model predicted values, giving the model a highly acceptable degree of accuracy. The graph shows accurately predicted high peaks for the months of of May and September of 2001, 2002 and 2003, and January of 2003. However, the model still misses a few of the smaller events, e.g., in the months of September 2000, May 2001, January, May and August 2003.

The cumulative graph for the runoffs in W4 (Figure 4-9) gives a very clear indication of the accuracy of the model in the abovementioned pasture. The curve for the measured values follows the curve for the model predicted values very closely as seen in the graph. The values are very close almost throughout the validation period, except for an instance in November 2002 and one in September 2003, where the measured values differ from the predicted values with a slightly greater margin.

The measured vs predicted scatter graph for W4 (Figure 4-10) indicates clearly the accuracy of the model with respect to pasture W4. Very few values on the graph are under-predicted, and the high proportionality also indicates the high accuracy of the values. The best fit trend line also matches quite closely with the 1-1 trend line, overall implying a good model performance for W4.

Among the native pastures, the model shows the least accuracy of performance on the Winter 3 (W3) pasture (Figure 4-11). The result graphs indicate the presence of some discrepancy between the measured and the predicted values for the month of July and October 2001, June, August, December 2002, and June, September and October 2003. For certain other months like September 2000, November 2001, February, March, April and November 2003, some less significant runoff events are missed by the model.

The cumulative runoff for W3 (Figure 4-12) is correspondingly reflective of the lower accuracy of the model on this pasture. The curves follow closely until May 2001. However, after this period the model over-predicts the runoff on three crucial occasions in September of 2001, 2002 and 2003 which causes the cumulative curves to sparse out rapidly.

The measured vs predicted scatter graph for the W3 (Figure 4-13) pasture indicates an overprediction of some of the values. It can be seen from the graph that the best fit trend line does not perfectly match the 1-1 trend line as it does in W4, which is the best performance of the model.

Phosphorus Load

The analysis of the model performance in the various pastures shows that the model tends to slightly overpredict the values of the peaks and misses a few smaller events, similar to the performance of the model on different pastures for runoffs. However, over NS-Ceff values overall are higher for the phosphorus load simulations, indicating the overall better performance of the model in predicting phosphorus loads

Among the model performances in the various summer pastures, the pasture with the most accurate model predictions is Summer 8 (S8) (Figure 4-14), with a NS-Ceff of 0.5960, an nMSE of 0.4040 and an RMSE of 5.35 kg. The graph depicting the S8 nutrient load indicates the close match between the measured and the predicted values. For this pasture, the most significant events take place during the months of May and September 2001, 2002 and 2003, and December 2002. Though the model mirrors the measured values with an acceptable degree of accuracy, there remain a few values that the model misses, as shown for the months of September 2000, May 2001, May 2002, and September 2003.

The cumulative load graph (Figure 4-15) also indicates a good level of accuracy in model performance. During the initial stages of the validation period, the predicted values closely mirror the measured values. However, around the period of September 2001 and 2002, there is an increase in the discrepancy between the values. This discrepancy varies until the end of the validation period.

The measured vs predicted scatter graph (Figure 4-16) for S8 shows a good prediction performance. Though a few of the values are under-predicted in the graph, the best fit trend line matches the 1-1 trend line tolerably well and is also indicative of the accuracy of the model in this regard.

Considering the pastures for which the performance of the model was less than completely satisfactory, the pasture where there appears to be maximum discrepancy between predicted and measured value is Summer 3 (S3) (Figure 4-17) with a low value of NS-Ceff (0.1484), with 0.8516 and 5.205 Kgs respective values of the nMSE and RMSE calculated. In this case, the model matched the high peak values for the months of May and September 2001, 2002 and 2003, and December 2002, though without the accuracy displayed by the model in other pastures. The model also missed the values in may 2001, 2002 and September 2003. The overall model however, catches the general trends of peaks and lows similar to the hydrology module.

The graph for the cumulative nutrient load (Figure 4-18) indicates the lower level of accuracy in the performance of the model for this particular pasture. The match or relationship between the parameters remains close until May-September 2002, after which, the model over-predicts a few values causing a gap between the measured and predicted curves.

The measured vs predicted scatter graph for S3 (Figure 4-19) indicates some under-prediction. A number of the data values are overpredicted, but the best fit trend line is below the 1-1 trend line and is not very accurate.

Overall, for the summer pastures, the model captures most of the significant events and the general trends of peaks and lows. This is noticed across all of the eight summer pastures. The detailed graphs of these are included in appendix A.

On comparing the model performance for the various native pastures with regards to nutrient loads, the pasture with the most accurate model performance is Winter 4 (W4) (Figure 4-20), with a NS-Ceff value of 0.6946, an nMSE value of 0.3054 and an RMSE value of approximately 0.8899 Kgs. In the graphs associated with this pasture, the values predicted values closely match the data measured at BIR. The model predicts values with very marginal discrepancy for the high load months of July and October of 2001 and 2002. In spite of missing a few of the smaller events, the model still maintains a highly acceptable level of accuracy and W4 is therefore among the best performances of the model in native pastures for nutrients.

The cumulative load graph for W4 (Figure 4-21) shows a close relationship between the predicted values and the measured values. In the middle of 2002, there is a slight discrepancy in the values, which can also be seen in some of the other months, namely, the end of 2001, 2003 and the beginning of 2002. However, overall, the curve for the predicted values closely matches the curve for measured values, thus indicating a good degree of accuracy in the model.

The measured vs predicted scatter graph for W4 (Figure 4-22) indicates a slight under prediction with regards to the data points on the graph. However, the best fit trend line indicates a slight under-fitting with respect to the 1-1 trend line.

Among the model performances for all of the native pastures, the pasture where the model was the least effective is Winter 8 (Figure 4-23) with a NS-Ceff value of -0.1755, an nMSE value of 1.1755 and an RMSE of approximately 1.0439 Kgs. According to the data shown in the graphs, the model closely predicts the values for the months of May 2001, May 2002, May and January 2003. The model overpredicts the values for September 2001, 2002 and 2003 and December 2002. However, it still manages to maintain an acceptable degree of accuracy as can be seen from the graphs.

The cumulative graph of the nutrient loads for W8 (Figure 4-24) indicates a discrepancy between the predicted and the measured values. The curve for the predicted values follows the curve for the measured values for the initial few months of the validation period. From August 2001, the curves start drifting apart as the discrepancy in the values increases. The measured vs predicted scatter graph for W8 (Figure 4-25) indicates a higher degree of overprediction than is seen on the graphs for the other native pastures. The best-fit line seems to be above the 1-1 trend line.

Forage Growth

Model testing was done for the period of 2001 – 2003. As mentioned earlier, the forage data recorded at BIR is not continuous and each of the readings for every month has range of values, and hence, the possibility of erroneous values. The model was tested only for the improved controlled pastures (Summer 1 and Summer 8) (Swain et al, 2007), which were maintained at a zero cattle stocking rate. Moreover, the cattle movement is a part of a management decision in QnD:BIR and for the testing period of the model, no management options were used during the simulation to efficiently gauge the accuracy of the model without any external influences. The testing procedure however is not as comprehensive as it was for hydrology and nutrients due to the discontinuous and varied nature of the measured data.

The overall performance of the model was gauged by comparing the simulated results with the range of measured values for the chosen pastures. Analysis of Summer 1 pasture (Figure 4-26) indicated that the model was acceptably accurate and within the measured data range for most of the testing period. It can be noticed that the model over-predicted the forage yield for a few months and missed one increase in yield growth over the testing period in September 2003. The NS- Ceff was calculated to be 0.2440 which is acceptable but does not reflect the variable nature of the measured data.

Analysis of Summer 8 pasture (Figure 4-27), revealed a similar trend with the model's overall performance was within acceptable limits. The NS-Ceff value was calculated as – 0.2930. An important observation of the model's design indicated that the simplistic empirical approach followed by the model, is unable to account for the different factors that influence the forage growth. However, the model overall was effective in simulating the growth trends of Bahia grass.

Summary of Model Testing

The model was tested against the BIR measured data for the period of 2001 - 2003. The graphs obtained are included in the appendix A. Moreover, several error estimation methods were used to gauge the performance of the model over the 16 experimental pastures which were explained in detail in chapter 3. After analyzing the output of all of the methods and graphs, though the model seems to perform good and bad over all of the pastures, largely, the model captures the trends of the peaks and lows, occasionally missing/over-predicting a few peaks/lows. The RMSE values do not vary largely over the pastures, and the cumulative and monthly graphs indicate that the model performance is within the acceptable limits of accuracy. Collectively, the model performed well, with error estimations within the acceptable limits of modeling standards.

Enterprise Wide Simulations and Scenario Analysis

The model development and testing have been discussed in the previous sections, which is a requirement to validate the authenticity of any model. This section is the actual application of the model for the whole beef cattle enterprise and the 68 pastures in the farm. The model was run for the period of 2000 – 2003 for the whole farm and the total runoff, phosphorus load, grass biomass and the monthly operational expenses of the model were measured under different simulated rainfall conditions apart from the measured rainfall which is provided as input.

The model was run for the whole farm simulation following the time schedule discussed earlier in chapter 3 with the move cows options being enforced every summer and winter to move the cows from summer to winter pastures and vice-versa. Moreover, apart from the actual rainfall, the conditions of less than regular rainfall and more than regular rainfall were also run as separate scenarios.

Scenario – 1: Measured Rainfall

The first scenario is the regular measured conditions of rainfall and temperature. The cows are alternated between the Summer 1-8 pastures during the summer and the Winter 1-8 pastures during the winter for the period of the run. The output values that are taken up for this analysis included total monthly runoff, total phosphorus load, total grass biomass and total operating amount available with the ranchers per month, with the assumption that BIR started out with \$1000000 as capital when the simulation period started. The operating income is not only an indicator of the ranch operating costs and incomes, but also serves as a pointer to the cow-calf ranch management operations, as they are the major influence in deciding the profitability of the ranch.

Scenario – 2: Low Rainfall

The second simulation involved reducing the amount of rainfall over the period of the run by calibrating the measured values of the rainfall input to 15 percent less than that of a regular period, hence causing more severe drought conditions. All other input parameters were kept the same as rainfall is the major driver of QnD:BIR, it was chosen as the parameter to run different scenarios for. Also the cow movement was differed and other non-experimental pastures were used to move the cows during the winter namely, South marsh west and South marsh center.

Scenario – 3: High Rainfall

The other end of the spectrum to lower rainfall is the higher rainfall year. The idea is to see if more rainfall necessarily has an effect on the profitability of the enterprise and on the general hydrology and nutrient loads of the region. However the cow movement in this case too is similar to the other scenarios, wherein, the cows are moved from summer or improved pastures to the unimproved pastures in the winter.

All of these scenario runs were run to provide an understanding of how the model can be useful both to researchers and the rancher to provide a starter for future predictions based on climate prediction data which can be continued as a part of this research.

Results and Discussion

The results of the whole farm simulation runs provided results which follow similar trends to those seen in the experimental pastures during the validation period, as can be seen from the graphs in Figure 4-28. The operating amount values are interesting due to the sinusoidal nature, which further implies that profitability over the longer term required more than just cow movement and calf sales, without provided excess support for the calves/cows to grow and flourish, Though some months make good profits, overall, in order to maintain sustainability, the conditions do need to be favorable or the operating costs setup within this model, must be reduced.

Table 4-1. List of values of Nash-Sutcliffe coefficient (Ceff), Normalized Mean Square Error and Root Mean Square Error (in million liters) for runoff in summer pastures.

	Summer1	Summer2	Summer3	Summer4	Summer5	Summer6	Summer7	Summer8
NS-Ceff	0.583	0.587	0.613	0.510	0.617	0.561	0.536	0.572
nMSE	0.417	0.413	0.387	0.490	0.383	0.439	0.464	0.428
RMSE	4.179	4.368	4.346	4.113	5.025	5.417	5.164	4.809
Ceff_m	0.57	0.5940	0.6210	0.5910	0.6260	0.5820	0.5380	0.5780

Table 4-2. List of values of Nash-Sutcliffe coefficient (Ceff), Normalized Mean Square Error and Root Mean Square Error (in million liters) for runoff in winter pastures.

	Winter1	Winter2	Winter3	Winter4	Winter5	Winter6	Winter7	Winter8
NS- Ceff	0.729	0.674	0.382	0.809	0.695	0.738	0.715	0.705
nMSE	0.271	0.326	0.618	0.191	0.305	0.262	0.285	0.295
RMSE	5.902	7.231	6.977	5.608	8.806	6.687	8.215	7.151
Ceff_m	0.656	0.604	0.491	0.663	0.616	0.633	0.649	0.618

Table 4-3. List of values of Nash-Sutcliffe coefficient (Ceff), Normalized Mean Square Error and Root Mean Square Error (in Kgs) for load in summer pastures.

	Summer1	Summer2	Summer3	Summer4	Summer5	Summer6	Summer7	Summer8
Ceff	0.539	0.436	0.148	0.464	0.368	0.337	0.444	0.596
nMSE	0.460	0.564	0.851	0.535	0.631	0.662	0.555	0.404
RMSE	5.680	4.623	5.205	5.233	6.479	5.537	6.940	5.359
Ceff_m	0.563	0.518	0.403	0.524	0.513	0.471	0.567	0.587

Table 4-4. List of values of Nash-Sutcliffe coefficient (Ceff), Normalized Mean Square Error and Root Mean Square Error (in Kgs) for load in winter pastures.

	Winter1	Winter2	Winter3	Winter4	Winter5	Winter6	Winter7	Winter8
Ceff	0.411	0.534	0.504	0.694	0.287	0.586	0.461	-0.175
Nmse	0.588	0.465	0.495	0.305	0.712	0.413	0.538	1.175
RMSE	1.321	1.436	1.511	0.889	3.106	1.552	2.239	1.0439
Ceff_m	0.383	0.511	0.436	0.567	0.476	0.572	0.529	0.303

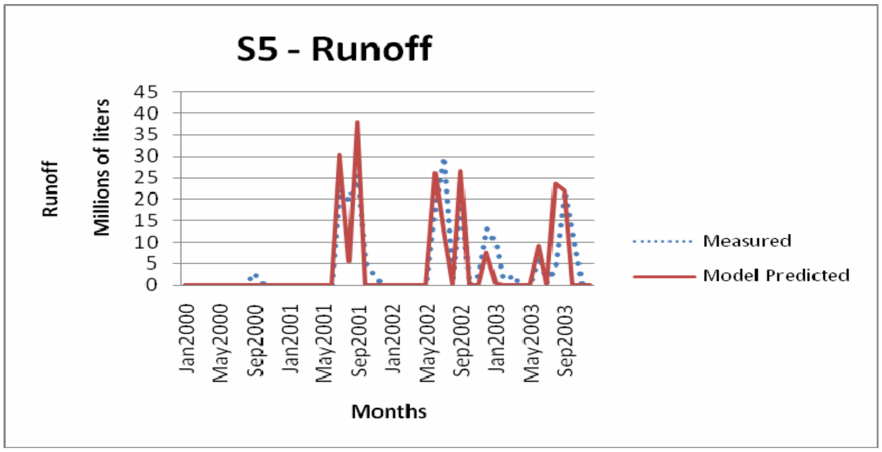


Figure 4-2.Monthly runoff in the Summer5 pasture

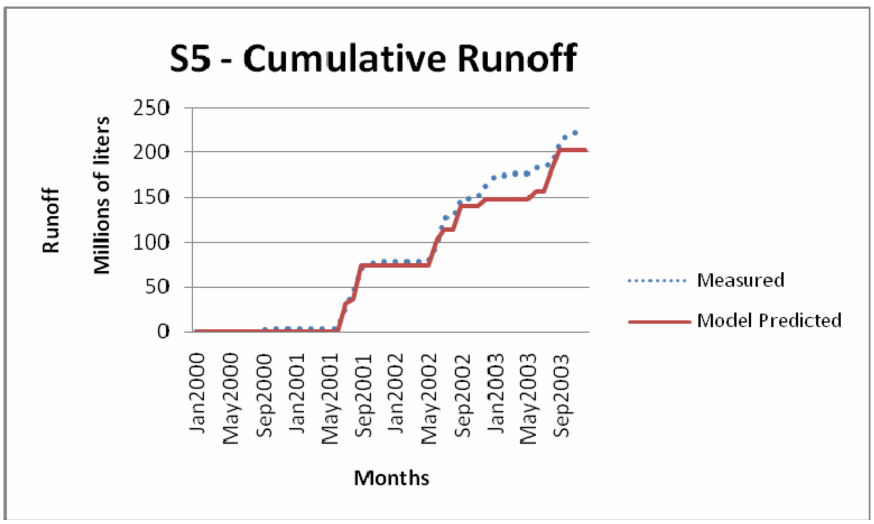


Figure 4-3.Cumulative runoff in the Summer5 pasture

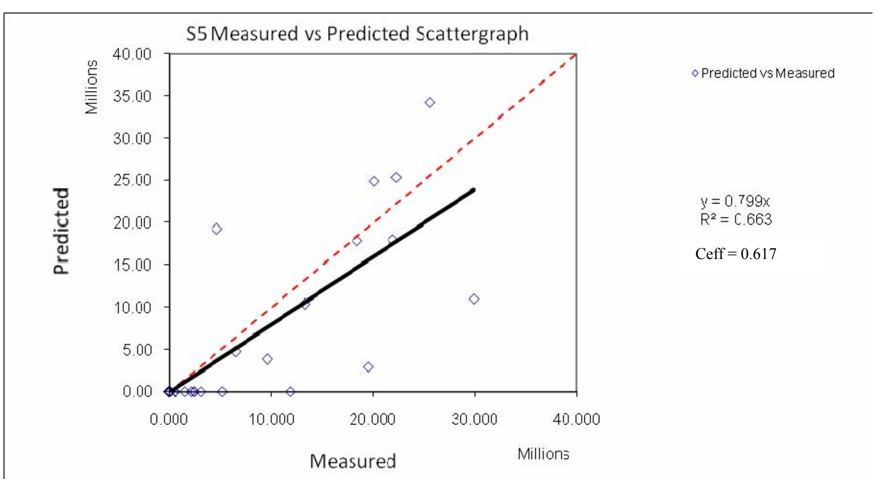


Figure 4-4. A measured vs predicted scattergraph for the Summer5 pasture runoffs

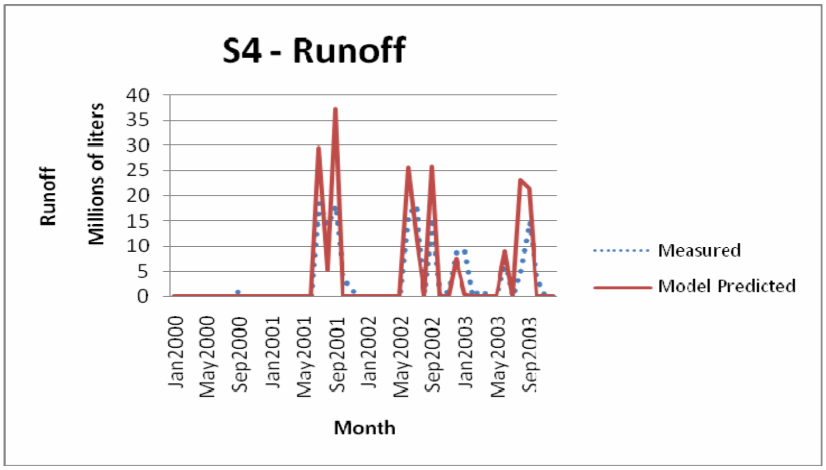


Figure 4-5.Monthly runoff in the Summer4 pasture

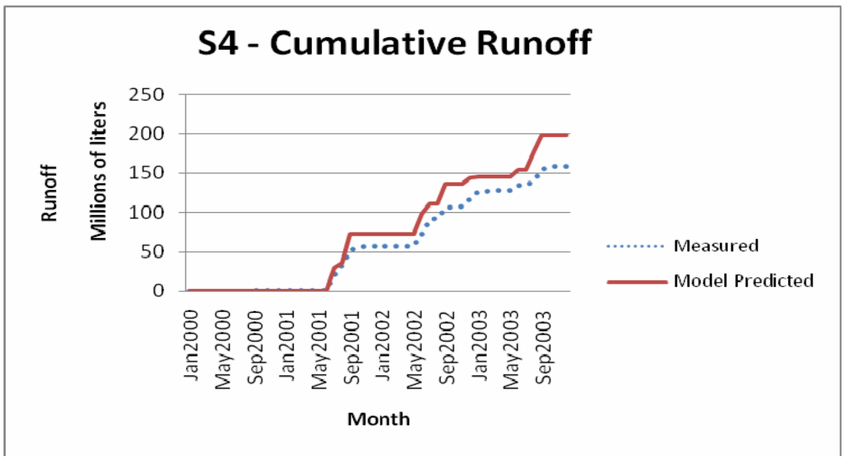


Figure 4-6. Cumulative runoff in the Summer4 pasture

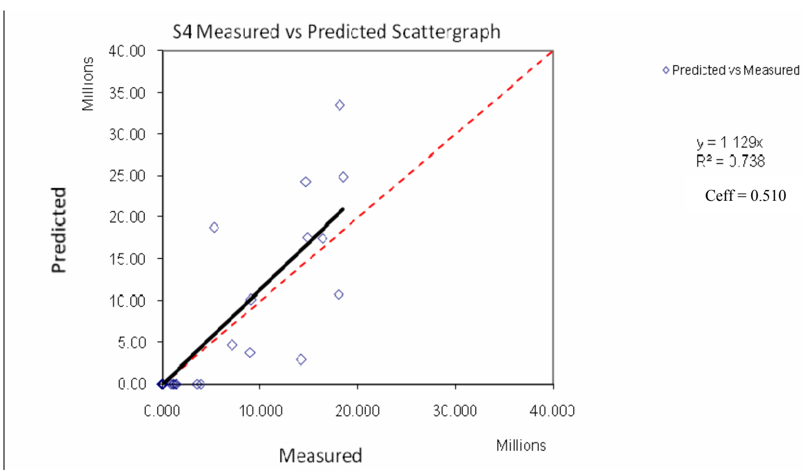


Figure 4-7. A measured vs predicted scattergraph for the Summer4 pasture runoffs

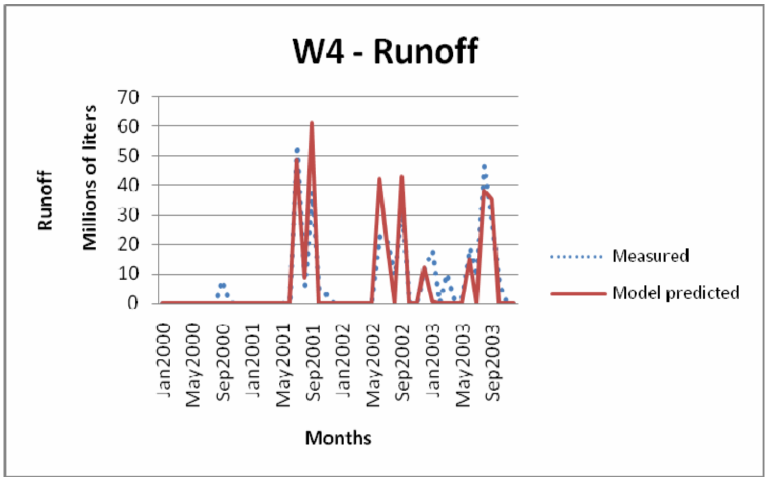


Figure 4-8.Monthly runoff in the Winter4 pasture

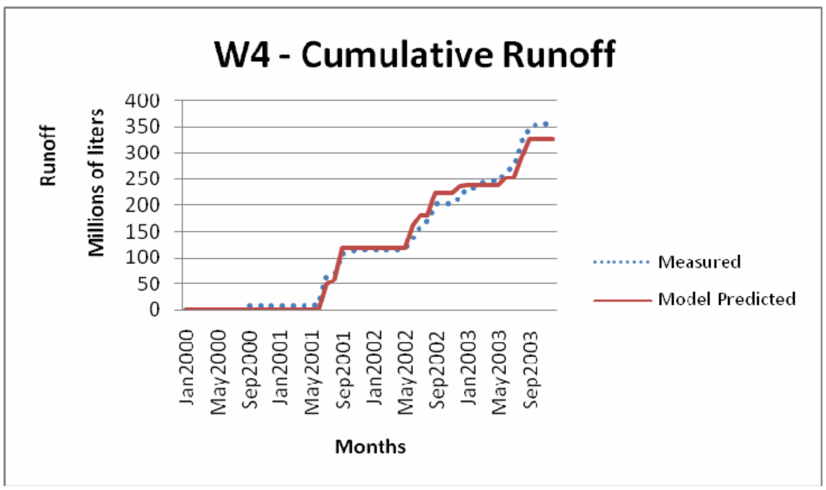


Figure 4-9.Cumulative runoff in the Winter4 pasture

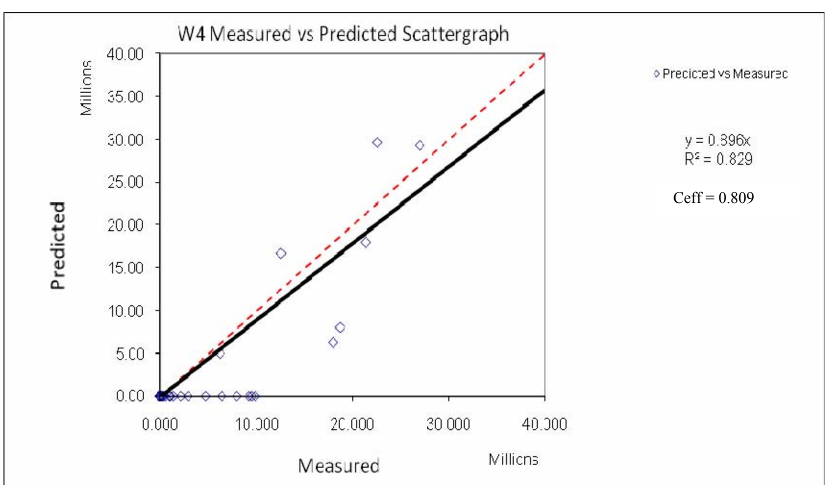


Figure 4-10. A measured vs predicted scattergraph for the Winter4 pasture runoffs

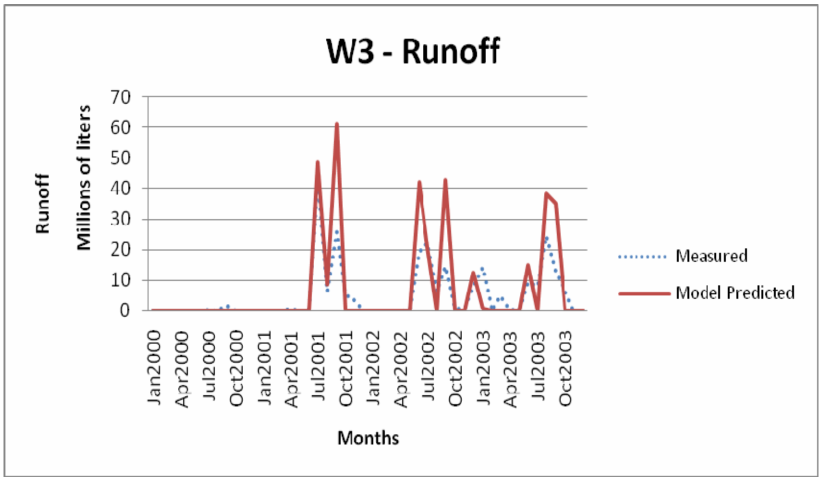


Figure 4-11.Monthly runoff in the Winter3 pasture

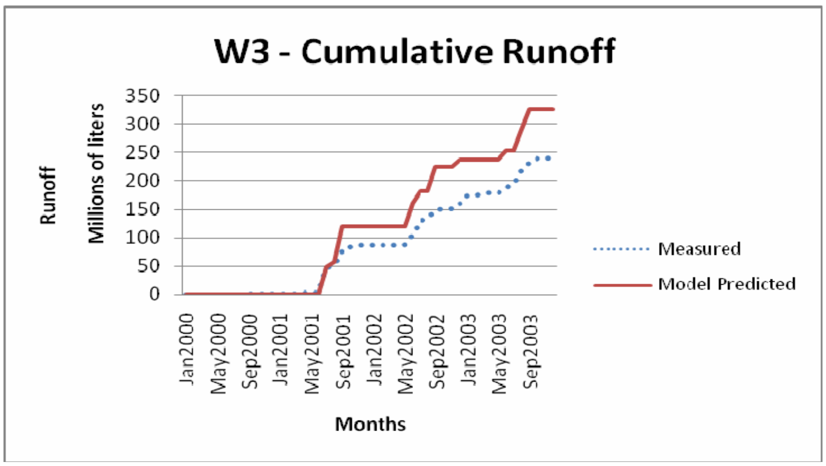


Figure 4-12.Cumulative runoff in the Winter3 pasture

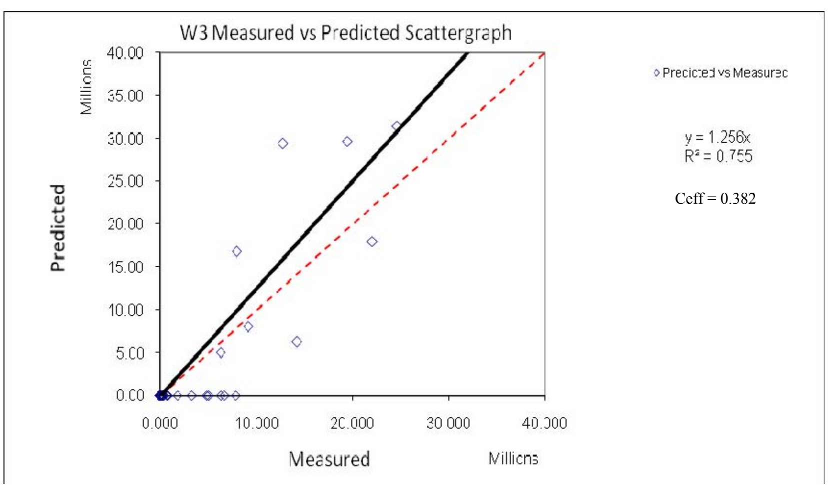


Figure 4-13. A measured vs predicted scattergraph for the Winter3 pasture runoffs

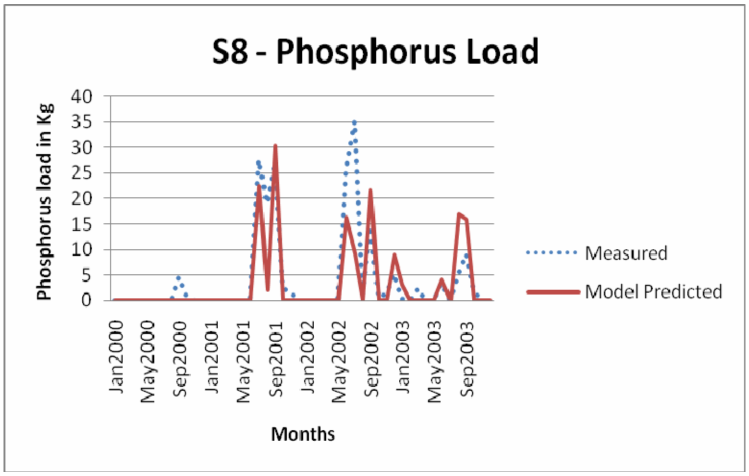


Figure 4-14.Monthly phosphorus load in the Summer8 pasture

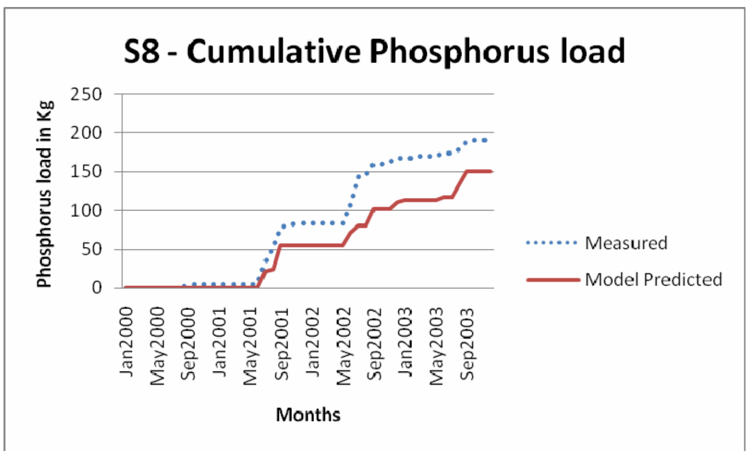


Figure 4-15.Cumulative phosphorus load in the Summer8 pasture

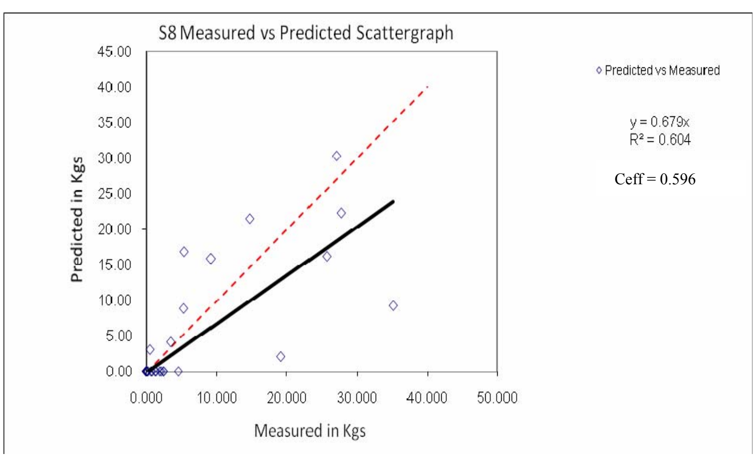


Figure 4-16. A measured vs predicted scattergraph for the Summer8 pasture Ph loads

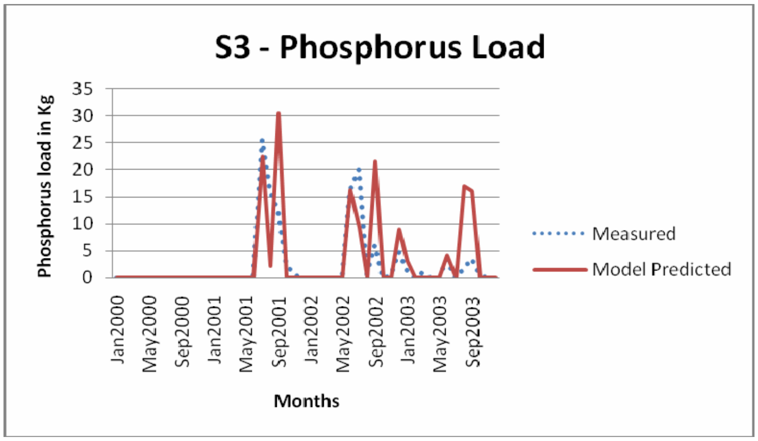


Figure 4-17.Monthly phosphorus load in the Summer3 pasture

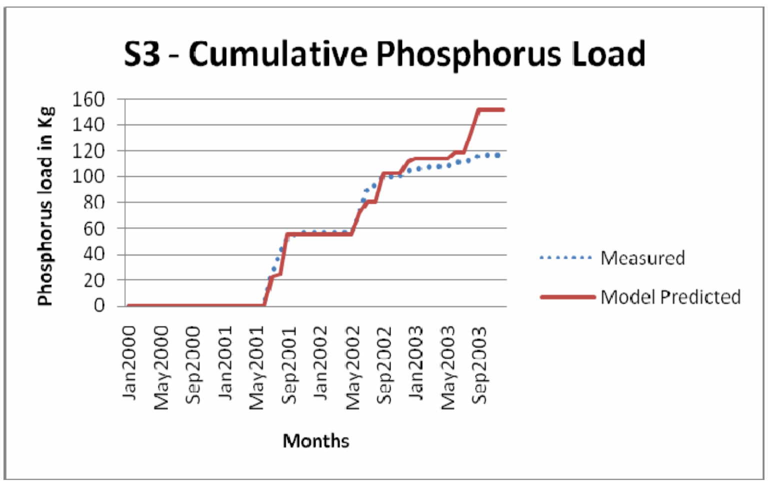


Figure 4-18.Cumulative phosphorus load in the Summer3 pasture

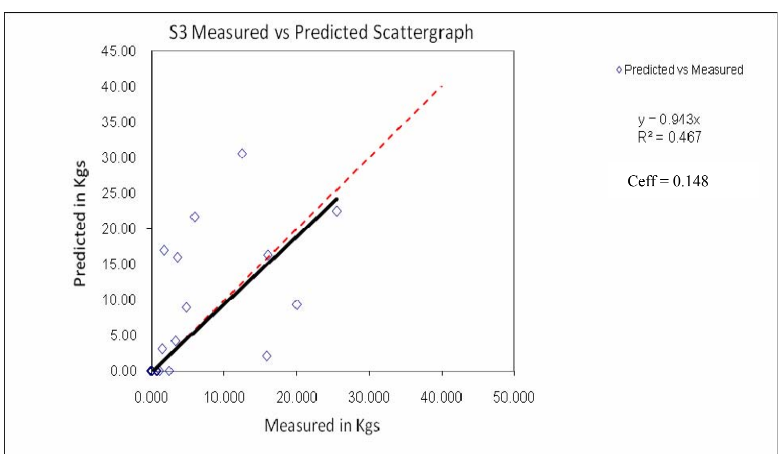


Figure 4-19. A measured vs predicted scattergraph for the Summer3 pasture Ph loads

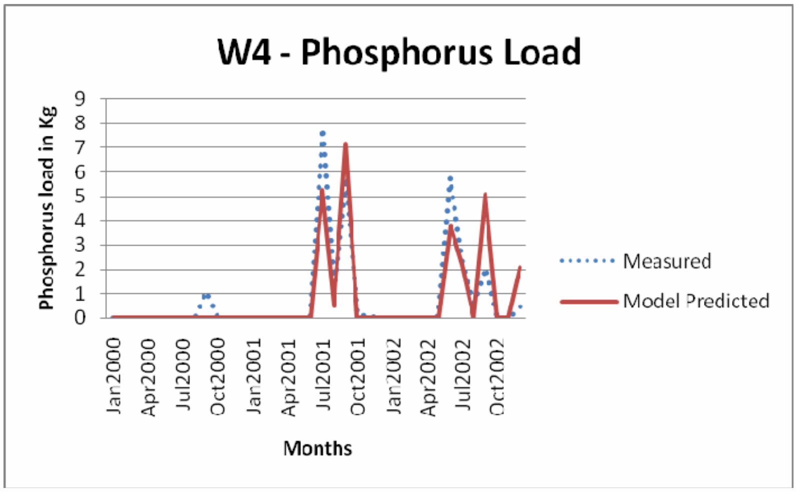


Figure 4-20.Monthly phosphorus load in the Winter4 pasture

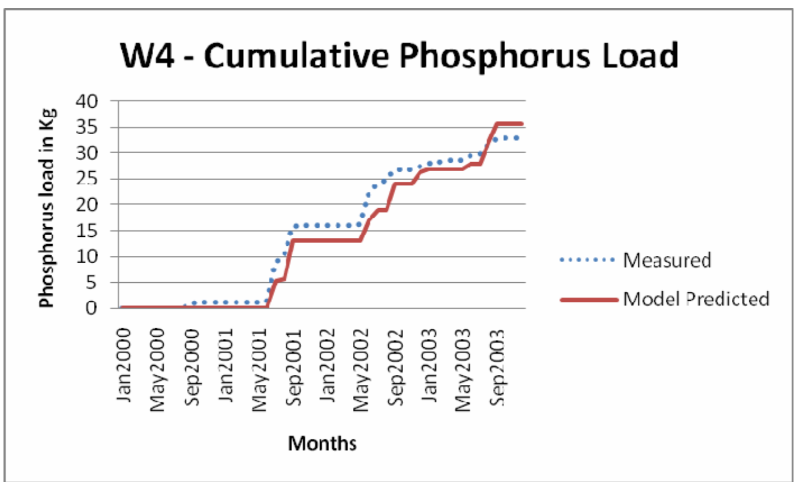


Figure 4-21.Cumulative phosphorus load in the Winter4 pasture

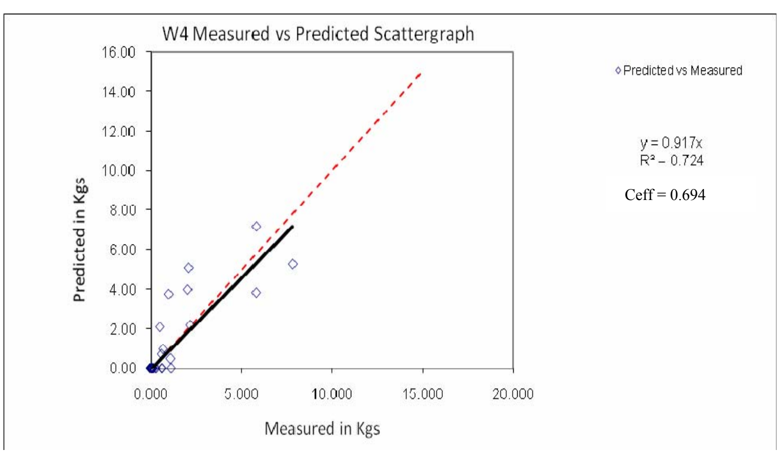


Figure 4-22. A measured vs predicted scattergraph for the Winter4 pasture Ph loads

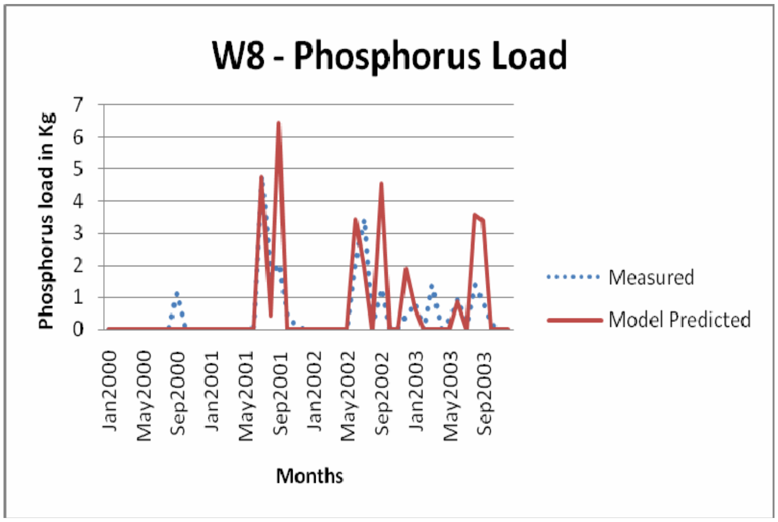


Figure 4-23.Monthly phosphorus load in the Winter8 pasture

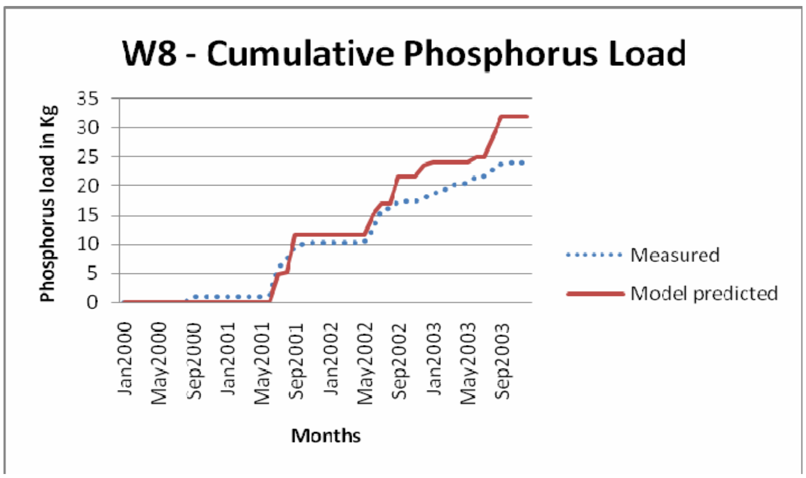


Figure 4-24.Cumulative phosphorus load in the Winter8 pasture

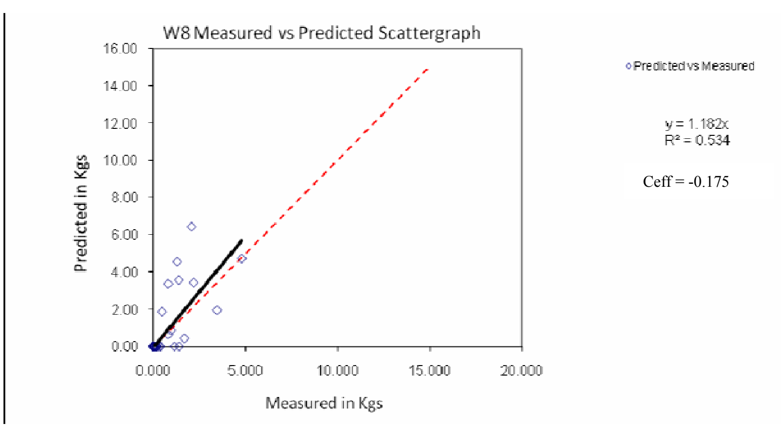


Figure 4-25. A measured vs predicted scattergraph for the Winter8 pasture Ph loads

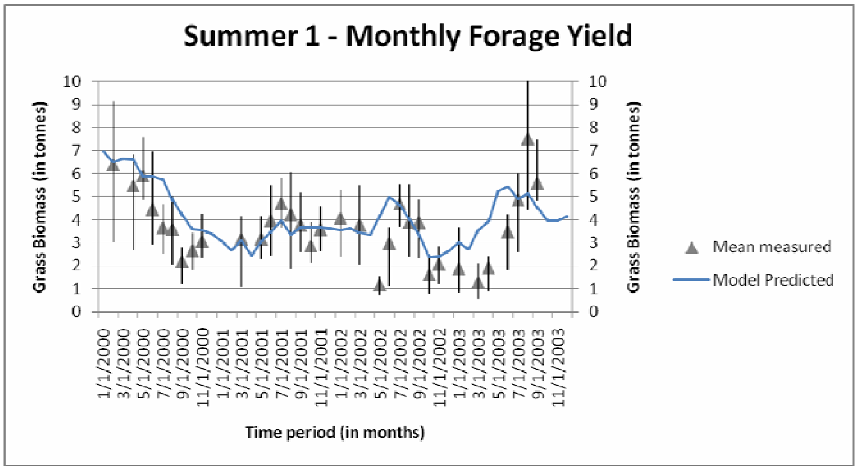


Figure 4-26.Monthly forage yield for the Summer 1 pasture

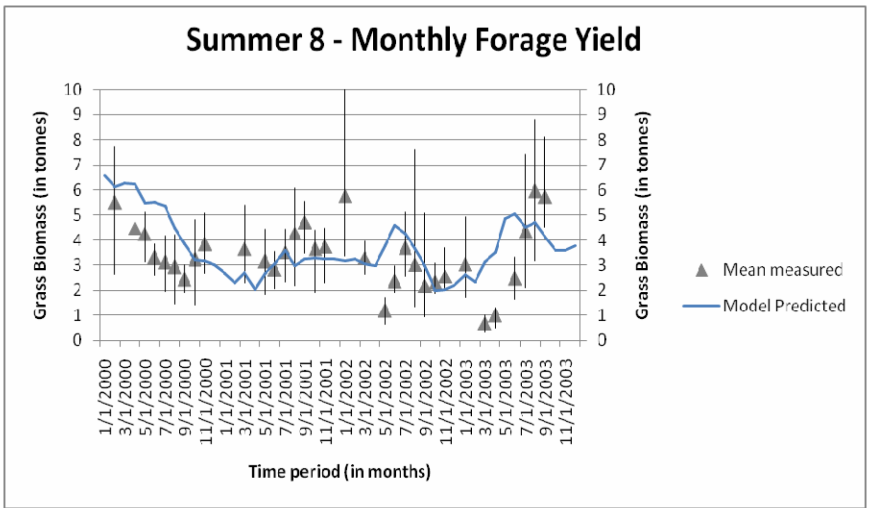
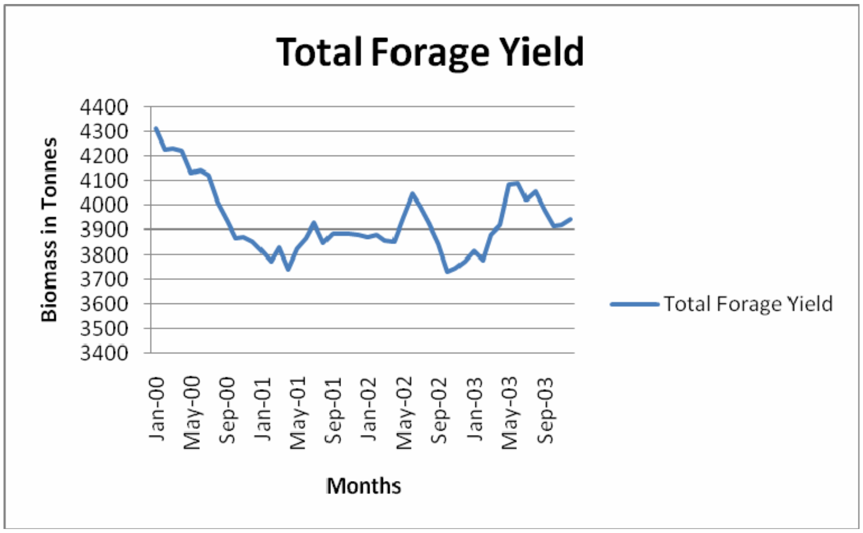
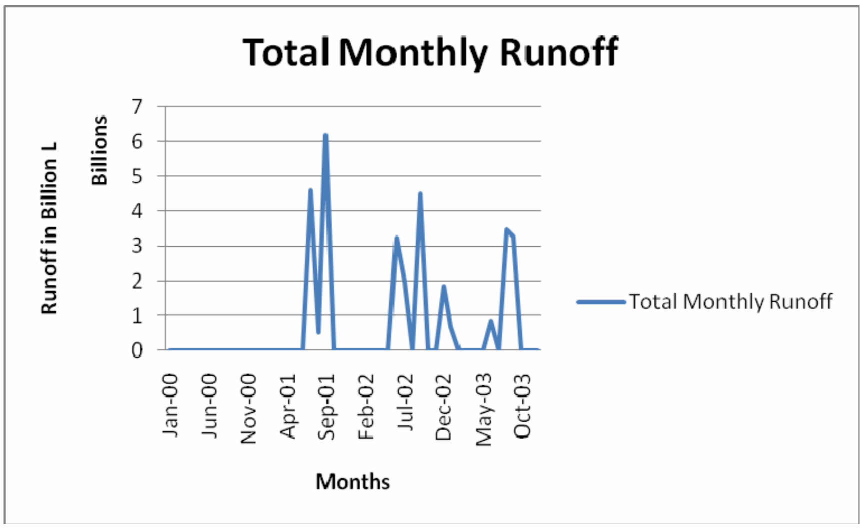
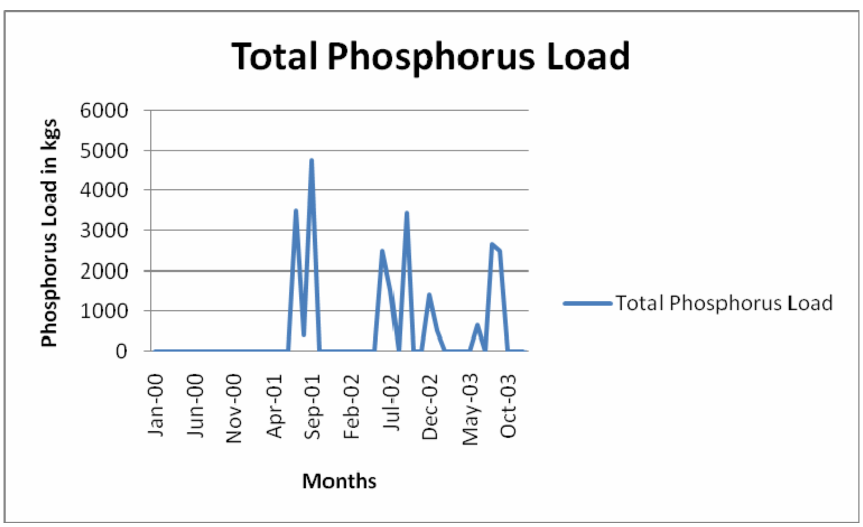


Figure 4-27.Monthly forage yield for the Summer 8 pasture


Total Forage Yield
Biomass in Tonnes
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
3400
Jan-00
May-00
Sep-00
Jan-01
May-01
Sep-01
Jan-02
May-02
Sep-02
Jan-03
May-03
Sep-03
Months
Total Forage Yield


Total Monthly Runoff
Runoff in Billion L
Billions
7
6
5
4
3
2
1
0
Jan-00
Jun-00
Nov-00
Apr-01
Sep-01
Feb-02
Jul-02
Dec-02
May-03
Oct-03
Months
Total Monthly Runoff


Total Phosphorus Load
Phosphorus Load in kgs
6000
5000
4000
3000
2000
1000
0
Jan-00
Jun-00
Nov-00
Apr-01
Sep-01
Feb-02
Jul-02
Dec-02
May-03
Oct-03
Months
Total Phosphorus Load

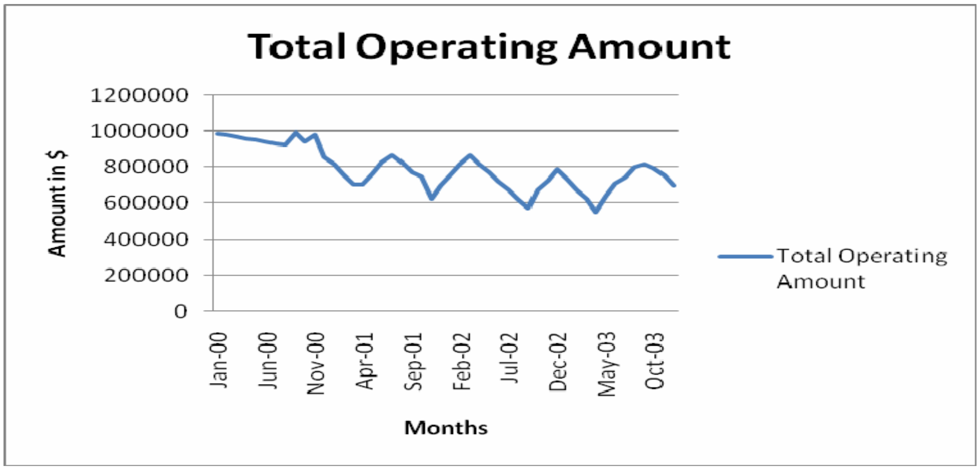


Figure 4-28. A) Total Forage Yield in the ranch B) Total monthly runoff in the ranch. C) Total phosphorus load in the ranch. D) Total operating amount at the ranch.

CHAPTER 5
CONCLUSION AND FUTURE WORK

Conclusions

Beef cattle enterprises and their management face several complex management and political challenges in an already fragile ecosystem of south Florida. On one end, there exists a struggle to maintain profitability and sustainability, and on the other, the effort to conserve the fragile ecosystem of the region and hence the political pressure from the environmental protection agencies. The current need is for a system that models the ecological issues of non point source pollution, and interprets the results in a user friendly decision oriented format.

The objective of this research was to design and develop one such decision support tool with the capability to model the ecological processes and interpret them as well. QnD: BIR was intended as a model that can be used by both the research community and the ranchers themselves with the intention of assisting the decision making process for managing the ranch. Moreover, the research site chosen, Buck Island Ranch (BIR), provides a unique setting for production-related, agro-ecological research. MAERC/BIR combines a research facility with a commercial-scale, beef cattle enterprise (10,300 acres) to explore the role of long-term ecological and social dynamics within sub-tropical grazing systems.

QnD: BIR is based on literature knowledge, actual laws of ecology, previous modeling efforts and expert wisdom from researchers and ranchers, the intended users of the model. The unique iterative model development methodology of QnD allows very close participation with the researchers and ranchers during the whole process of model development to cater it to their requirement. Moreover, the model is developed as an enterprise wide model, to be used on all of the pastures within MAERC/BIR. The scale is yet another aspect that makes QnD:BIR unique.

Once the development stage was completed, QnD:BIR was tested on environmental data from BIR for the period of 2000 – 2003 for sixteen experimental pastures including both improved and native pastures. Specifically, QnD:BIR simulation results of monthly runoff, phosphorus load and forage yield were compared with comparable field-scale data. After analyzing the output of all of the statistical error estimation methods and graphs, largely, the model captures the trends of the peaks and lows, occasionally missing/over-predicting a few peaks/lows. The hydrology and nutrients simulations generally follow the trend mentioned above. The forage yield simulations are also to the most part accurate and within the range of the measured values. Moreover, the statistics of error estimation also indicate that the model's performance is within the acceptable limits, given the coarse monthly time step. The model also has added modules to simulate ranch cow/calf production and the incomes and expenditures management which result in making it a complete enterprise wide decision support tool.

Future Research Recommendations

This modeling effort provided generally acceptable results and a helpful decision support tool for researchers studying sustainable ranching and ranchers to assist them in managing the ranch operations. However, as in any modeling effort, there is scope for future advancements within the model. QnD:BIR design methodology allows such advancements to be integrated easily into the model. The following are some recommendations for future work in this area.

Integrate Future Climate Predictions and Analyzing Different Scenarios

Climate prediction data from the Southeast Climate Consortium (SECC) can be integrated into the model to simulate future ranch operation and ecological trends. The climate predictions of future rainfall and temperature can be used as external input to the model. Various management scenarios can be run on the model. The analysis of the output would assist the ranch managers to assess the future of the ranch operation and help them prepare for it.

Improvement of the Cattle Production Module

The model currently has basic relationships governing cow production and movement. More research could be done into various factors influencing the cow/calf production operation ranging from buying of pregnant Heifers to culling of older cows. Moreover, detailed cow movement records are being collected and analyzed recently at MAERC/BIR. This can be used to further improve the cow herd movement simulations under various scenarios.

Integration of a More Complex Model into QnD

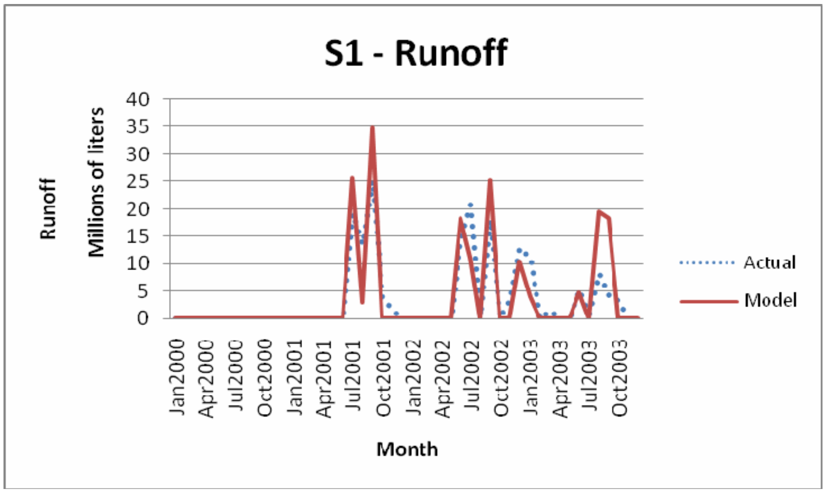
The hydrology and nutrient systems of QnD:BIR are developed using a simplistic approach. In order to more accurately model the hydrology of this region, more complex models like ACRU 2000 or the Century model can be integrated into QnD such that QnD:BIR uses the complex structure of these models and their outputs to better analyze their effect on the ranch operations of MAERC/BIR.

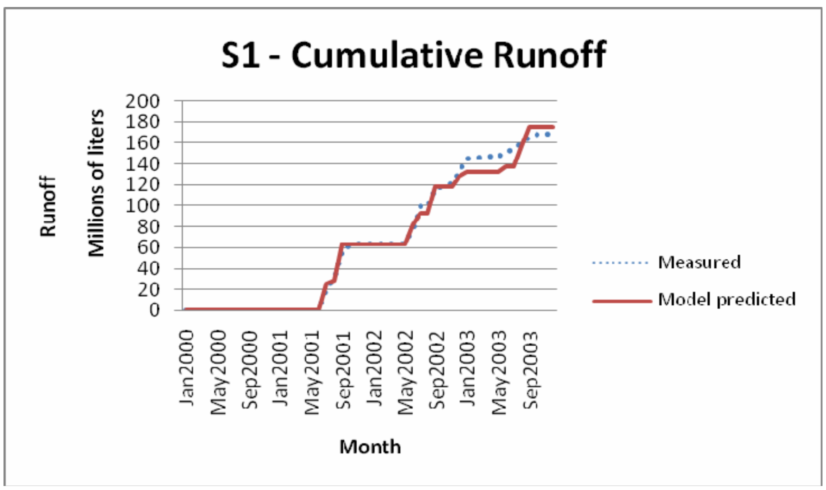
Integration of a More Advanced GIS Application Programmable Interface for Java

During the course of development and testing of this model, it can be noted that the GIS interface that is used in QnD:BIR is an older version and does not allow the developer to use the complete range of GIS capabilities. GIS is a powerful tool in spatial analysis, and further exploration of some of the advanced features of GIS can empower the model to be more spatially aware. This feature would help the model better gauge the topology of the region and hence better predict the hydrology of the area. Moreover, a more advanced GIS link would also enable the use of more than one principal layer to select and run the model simulations and hence expand the modeling capacity of the model.

Overall, QnD:BIR modeling effort is a synthesis of both scientific data and expert knowledge to create an easy to use decision support system with applications in education and future research in modeling.

APPENDIX A
MODEL RESULTS AND GRAPHS





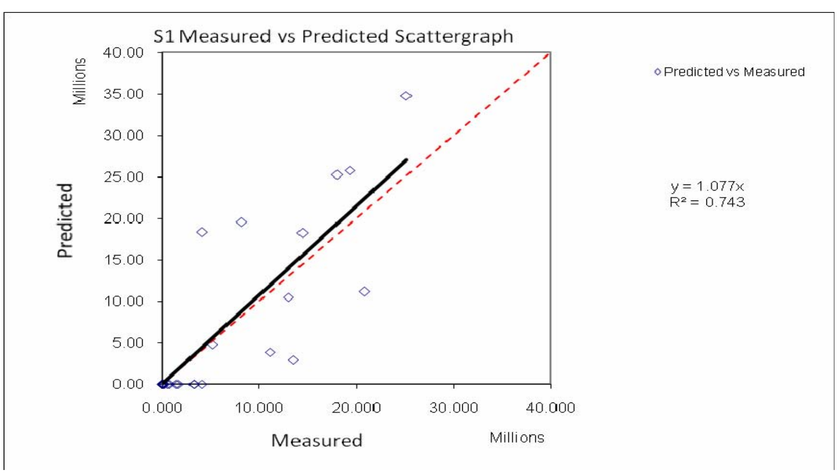
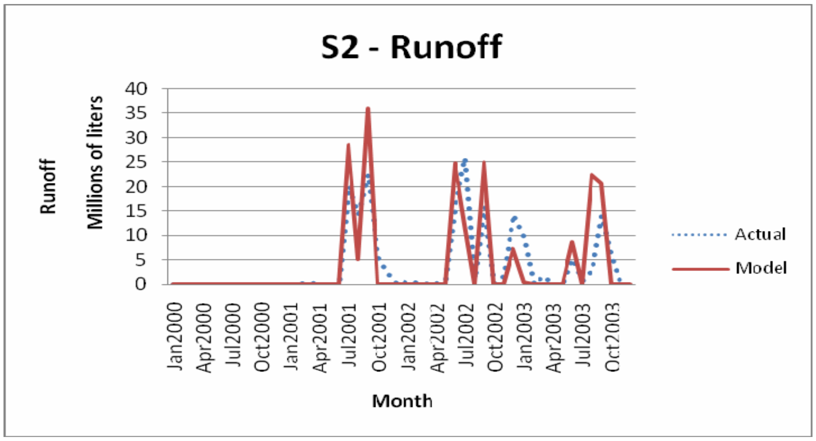
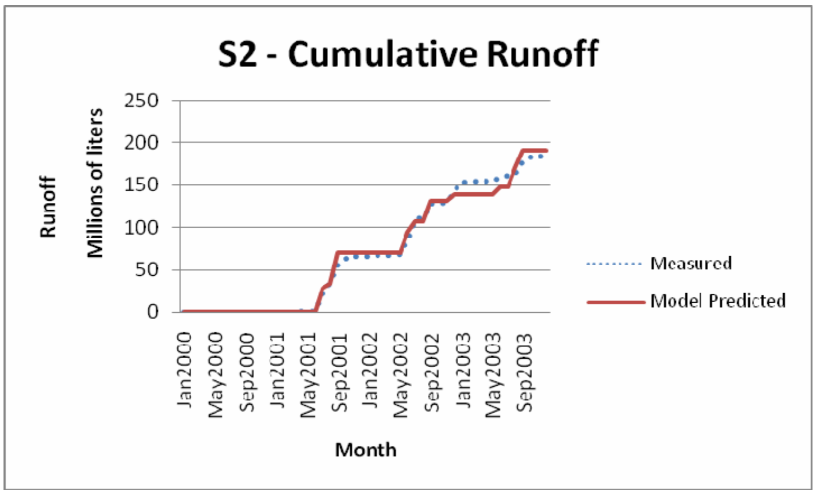


Figure A-1. A) Monthly runoff in the Summer1 pasture. B) Cumulative runoff in the Summer1 pasture. C) A measured vs predicted scattergraph for the Summer1 pasture runoffs





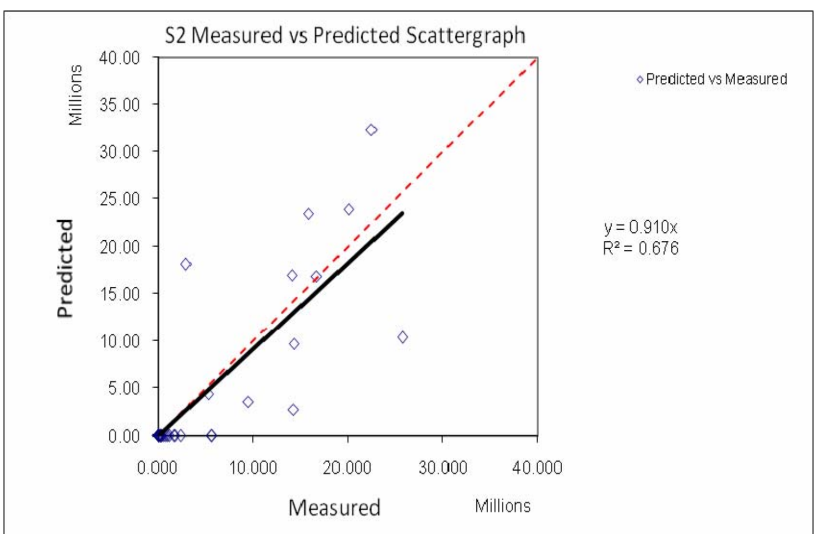


Figure A-2. A) Monthly runoff in the Summer2 pasture. B) Cumulative runoff in the Summer2 pasture. C) A measured vs predicted scattergraph for the Summer2 pasture runoffs

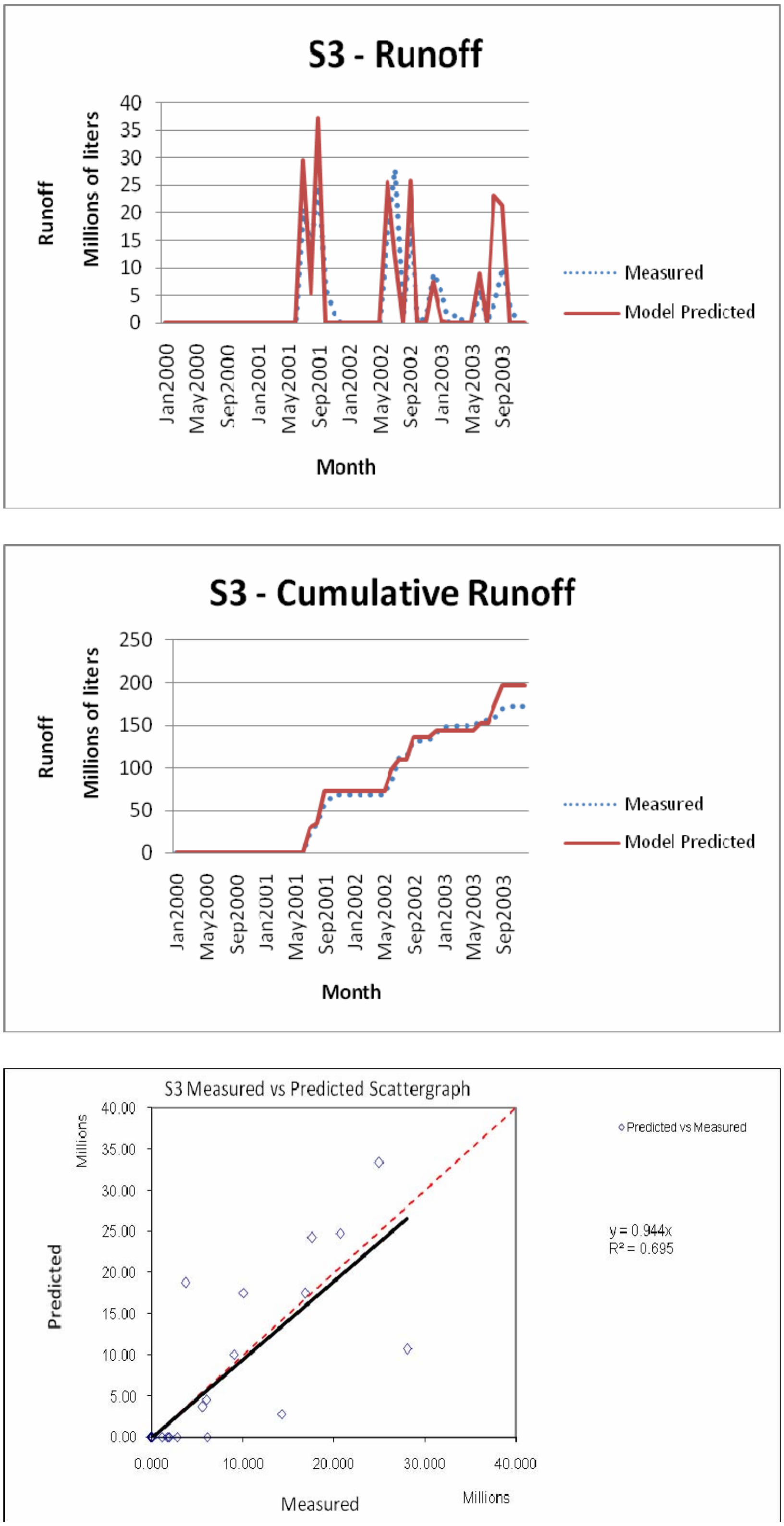


Figure A-3. A) Monthly runoff in the Summer3 pasture. B) Cumulative runoff in the Summer3 pasture. C) A measured vs predicted scattergraph for the Summer3 pasture runoffs

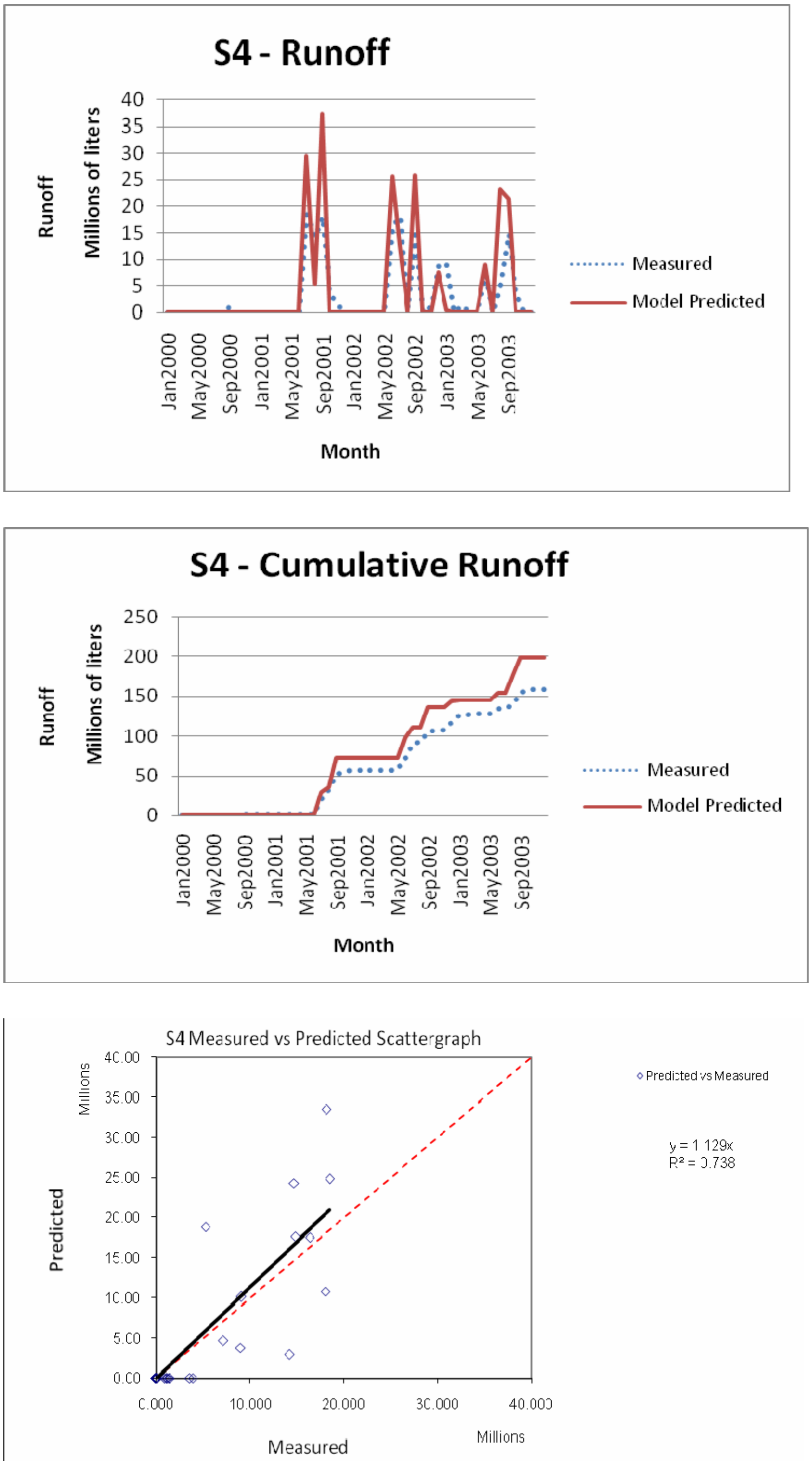
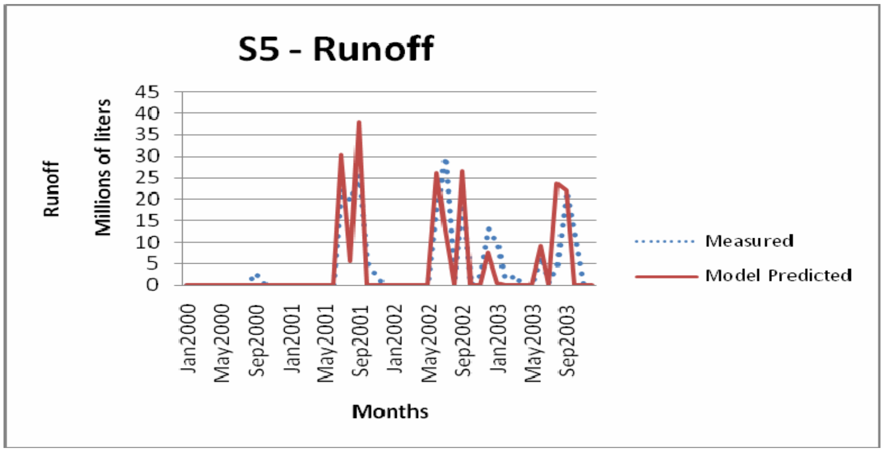
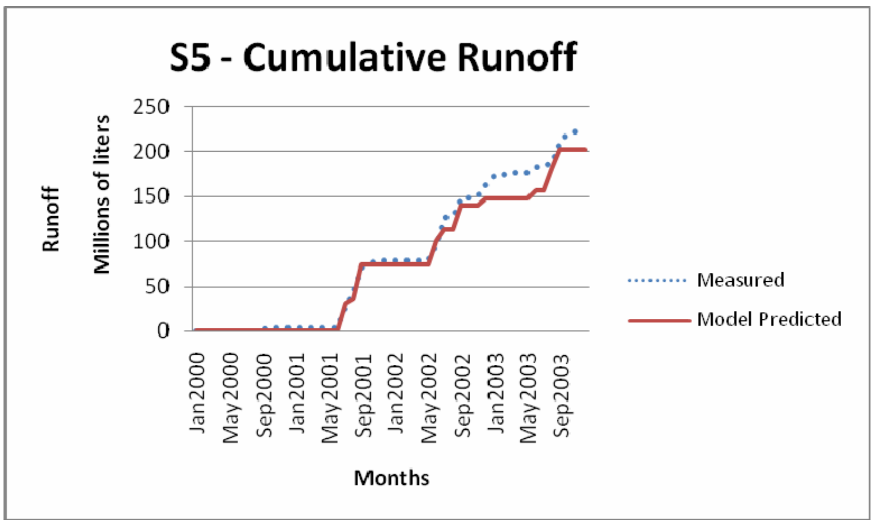


Figure A-4. A) Monthly runoff in the Summer4 pasture. B) Cumulative runoff in the Summer4 pasture. C) A measured vs predicted scattergraph for the Summer4 pasture runoffs





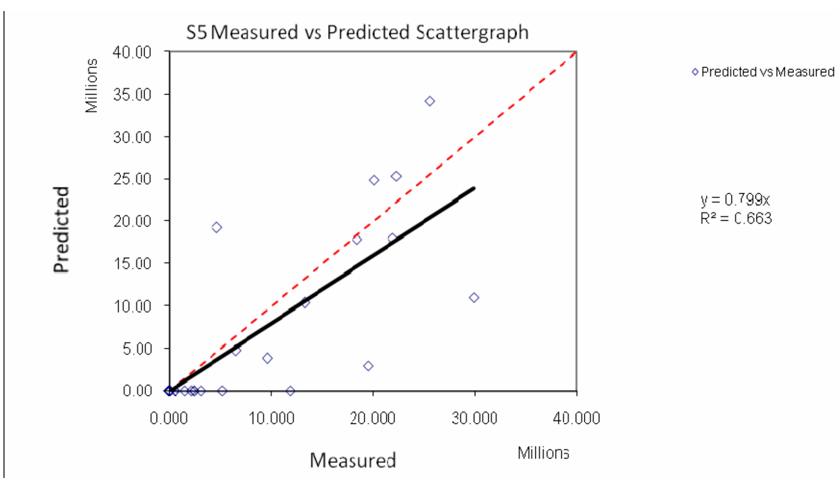
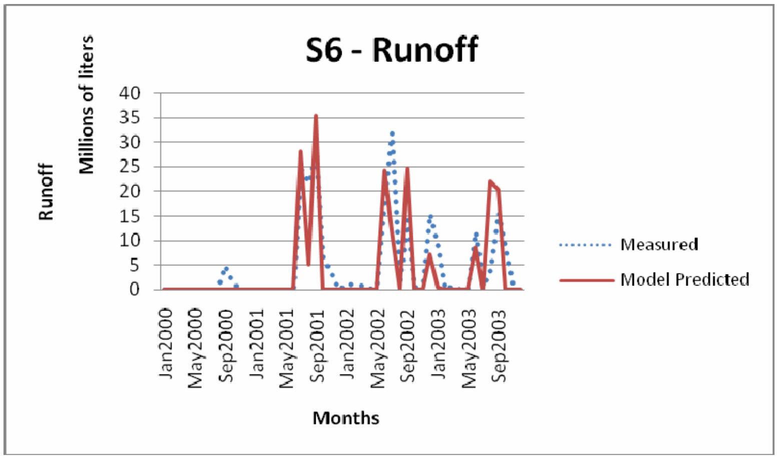
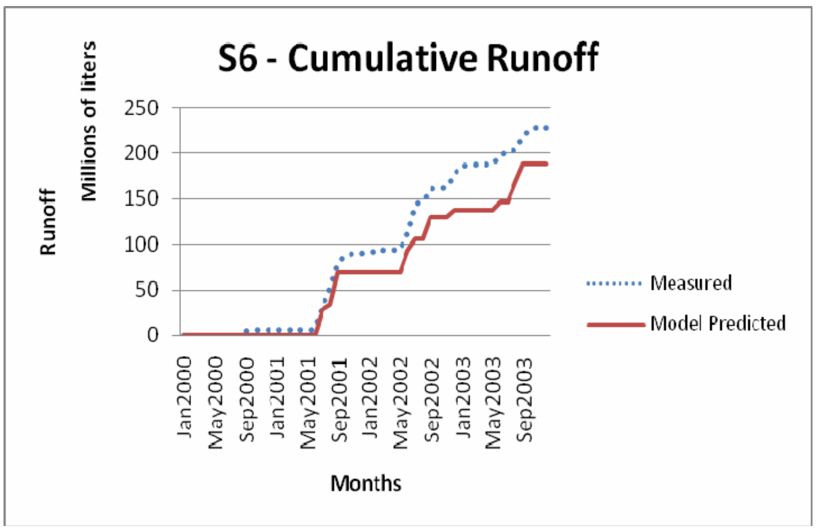


Figure A-5. A) Monthly runoff in the Summer5 pasture. B) Cumulative runoff in the Summer5 pasture. C) A measured vs predicted scattergraph for the Summer5 pasture runoffs





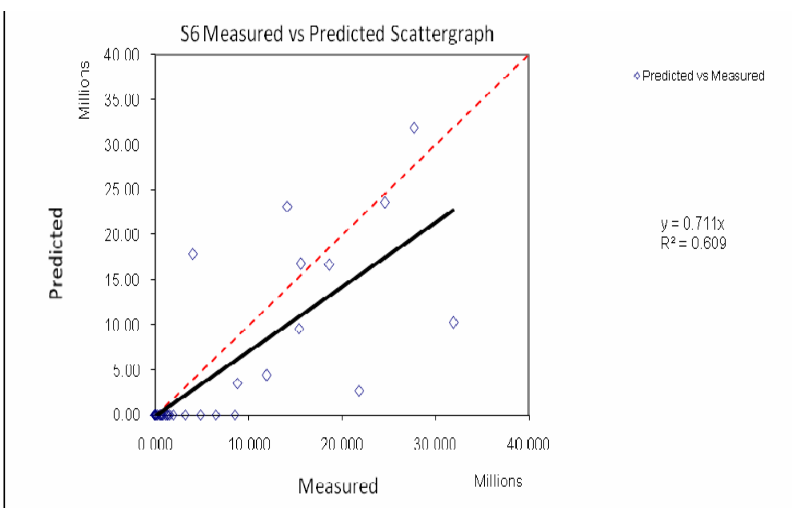
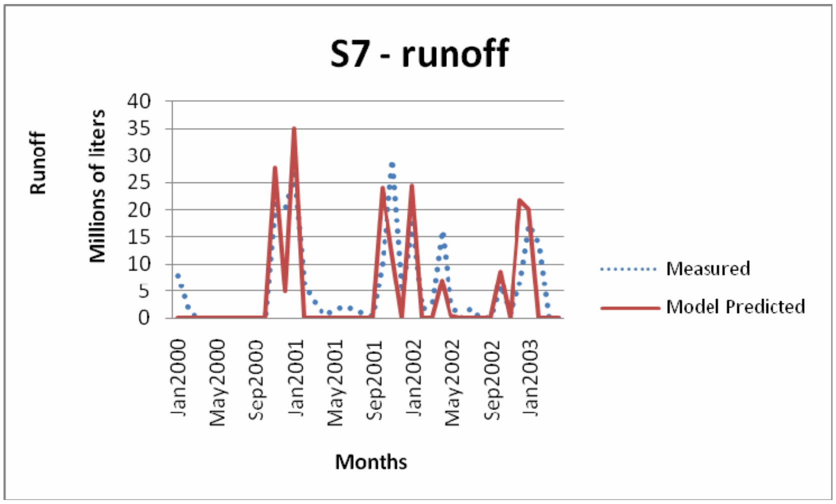
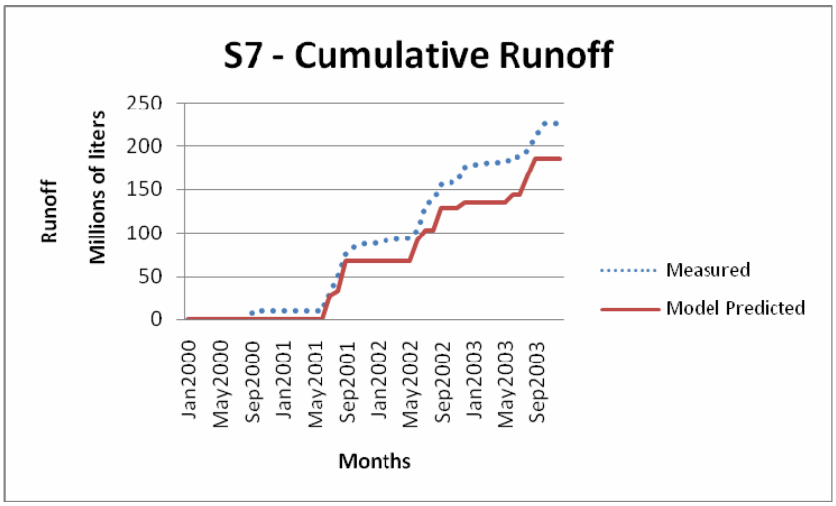


Figure A-6. A) Monthly runoff in the Summer6 pasture. B) Cumulative runoff in the Summer6 pasture. C) A measured vs predicted scattergraph for the Summer6 pasture runoffs





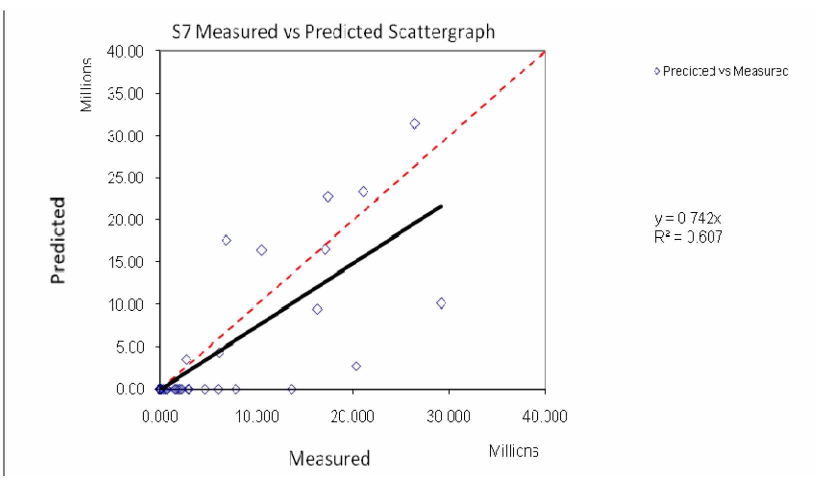
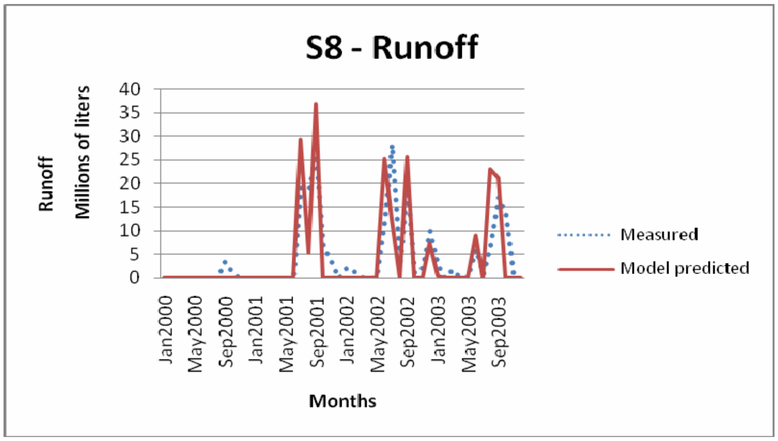
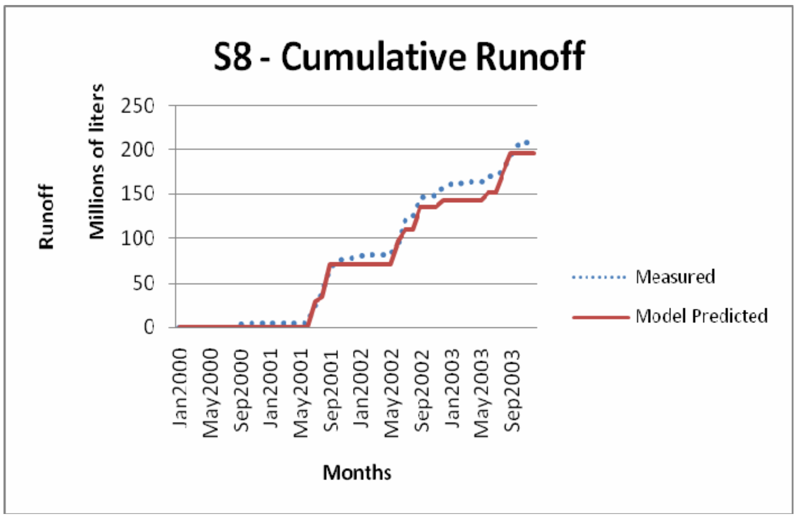


Figure A-7. A) Monthly runoff in the Summer7 pasture. B) Cumulative runoff in the Summer7 pasture. C) A measured vs predicted scattergraph for the Summer7 pasture runoffs





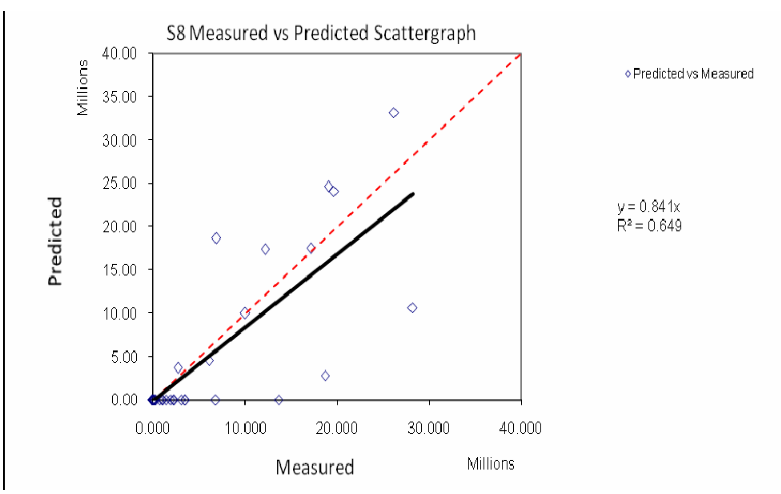


Figure A-8. A) Monthly runoff in the Summer8 pasture. B) Cumulative runoff in the Summer8 pasture. C) A measured vs predicted scattergraph for the Summer8 pasture runoffs

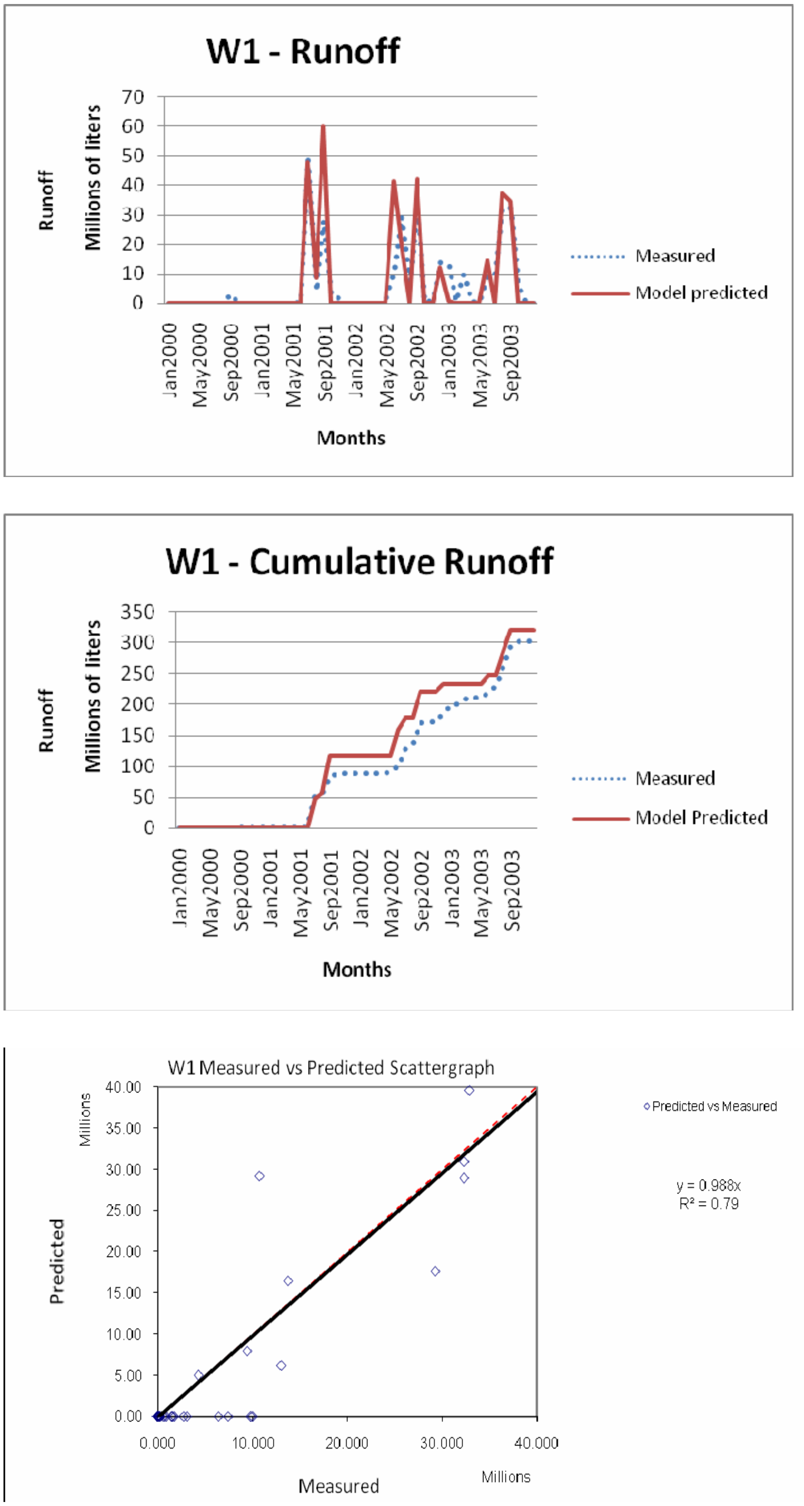


Figure A-9. A) Monthly runoff in the Winter1 pasture. B) Cumulative runoff in the Winter1 pasture. C) A measured vs predicted scattergraph for the Winter1 pasture runoffs

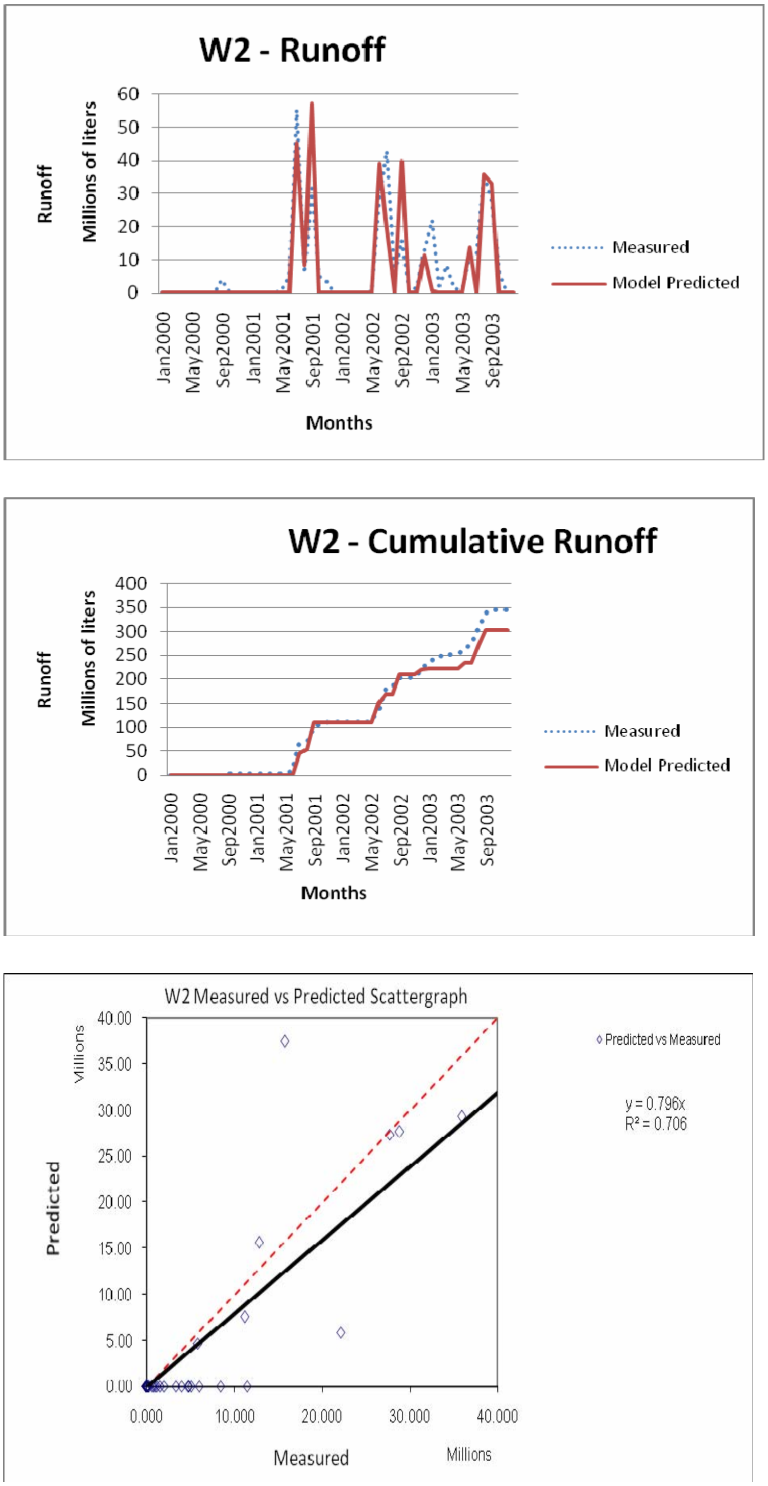


Figure A-10. A) Monthly runoff in the Winter2 pasture. B) Cumulative runoff in the Winter2 pasture. C) A measured vs predicted scattergraph for the Winter2 pasture runoffs

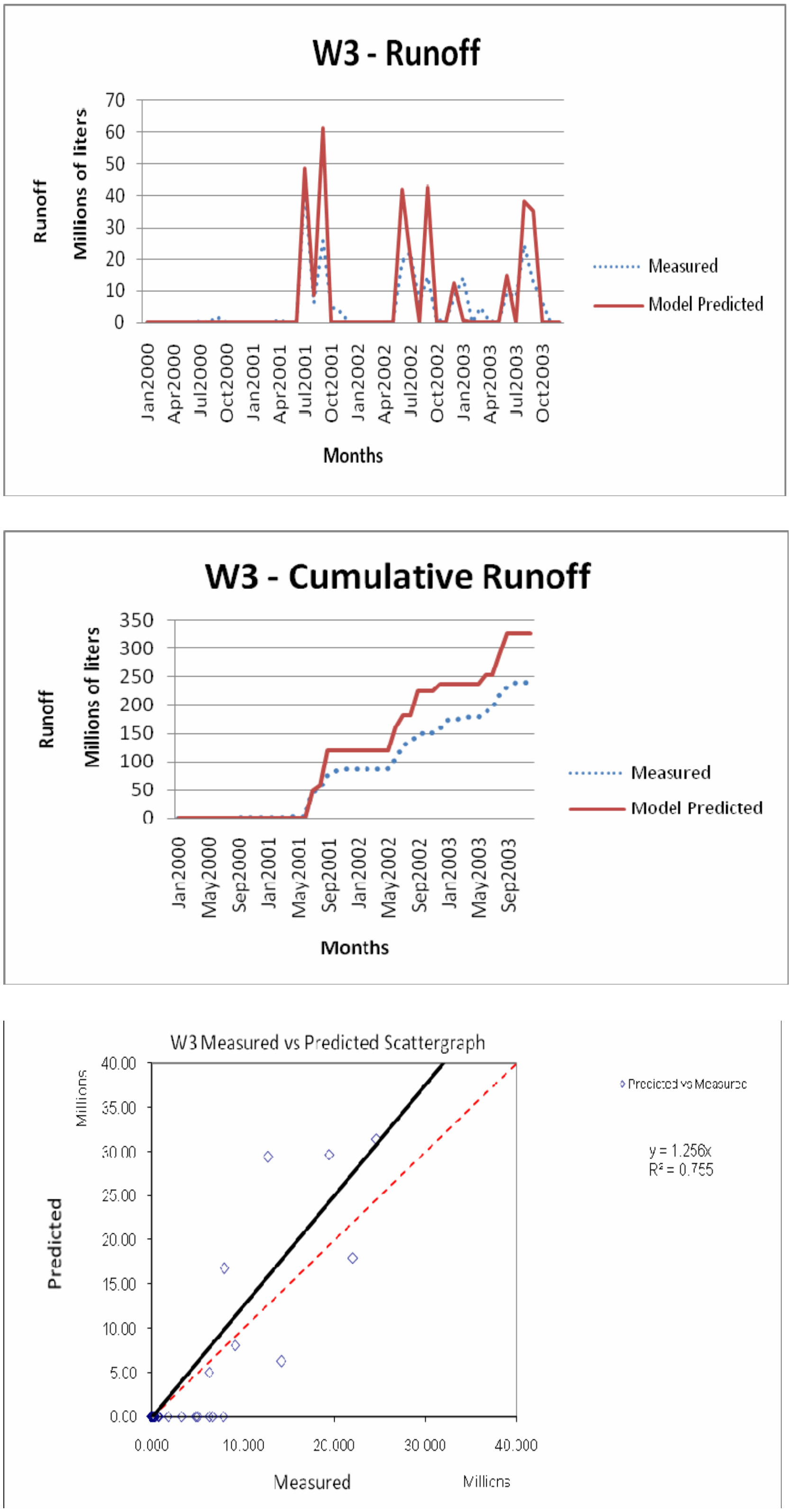
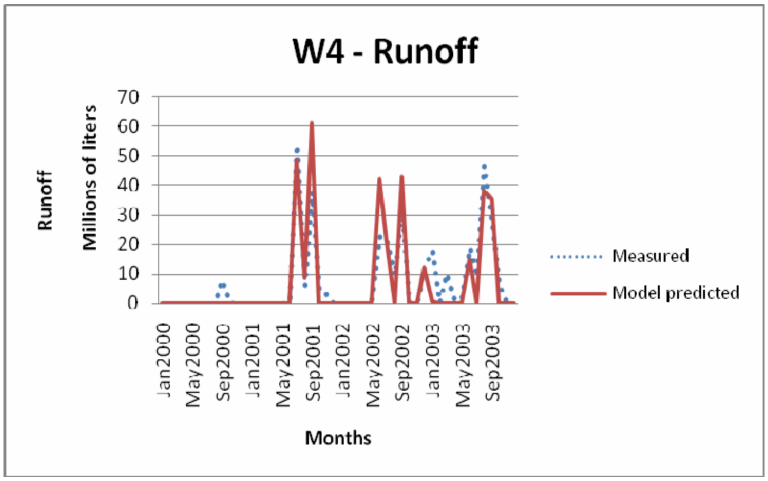
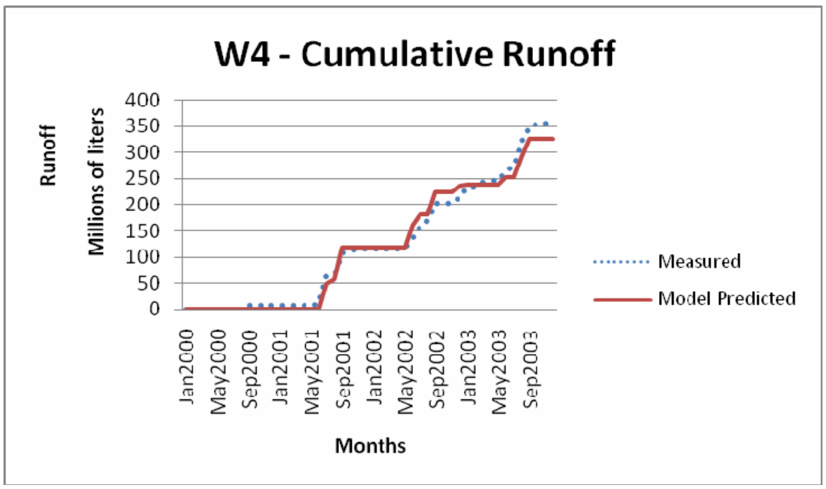


Figure A-11. A) Monthly runoff in the Winter3 pasture. B) Cumulative runoff in the Winter3 pasture. C) A measured vs predicted scattergraph for the Winter3 pasture runoffs





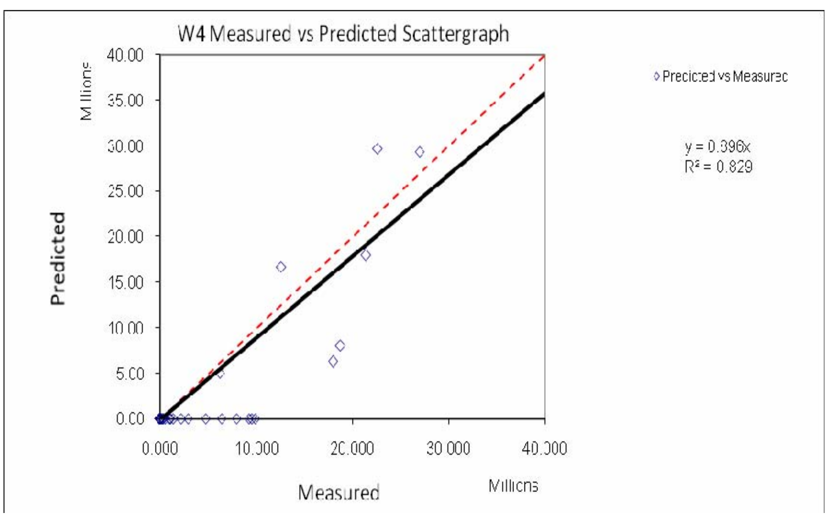
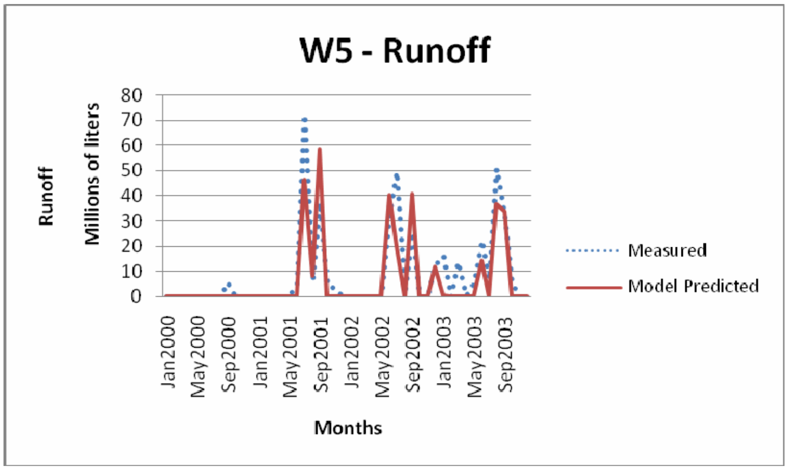
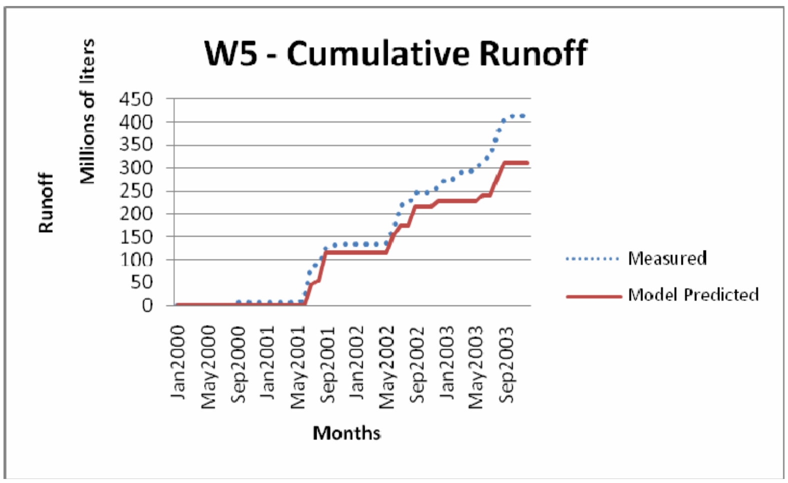


Figure A-12. A) Monthly runoff in the Winter4 pasture. B) Cumulative runoff in the Winter4 pasture. C) A measured vs predicted scattergraph for the Winter4 pasture runoffs





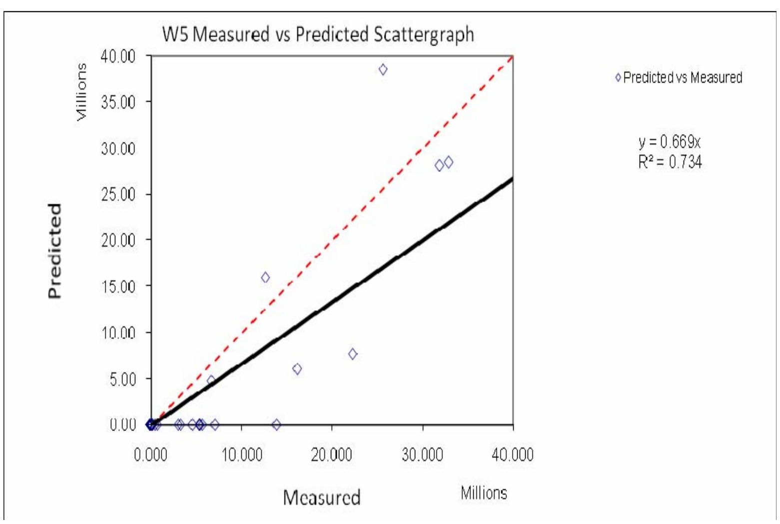
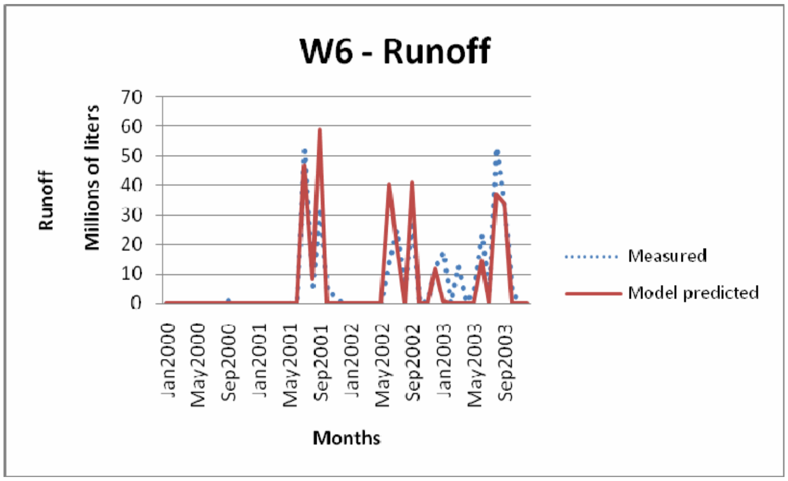
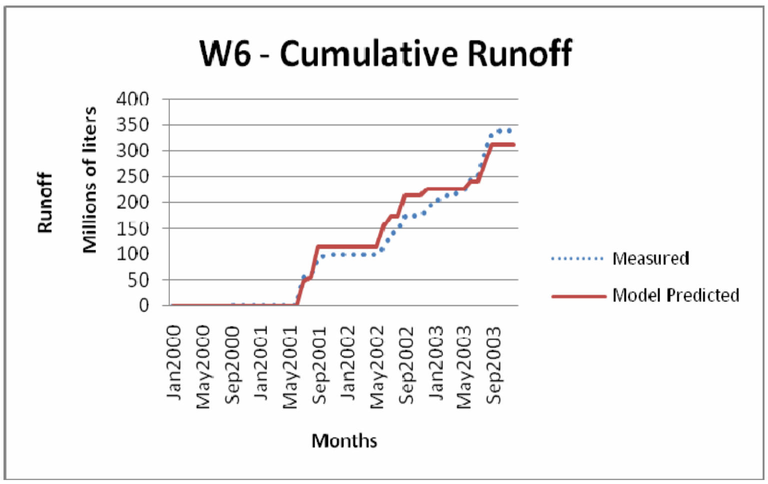


Figure A-13. A) Monthly runoff in the Winter5 pasture. B) Cumulative runoff in the Winter5 pasture. C) A measured vs predicted scattergraph for the Winter5 pasture runoffs





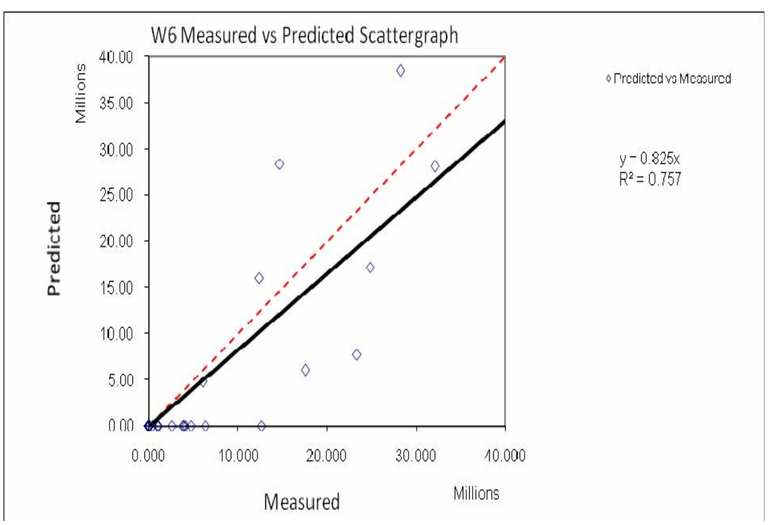


Figure A-14. A) Monthly runoff in the Winter6 pasture. B) Cumulative runoff in the Winter6 pasture. C) A measured vs predicted scattergraph for the Winter6 pasture runoffs

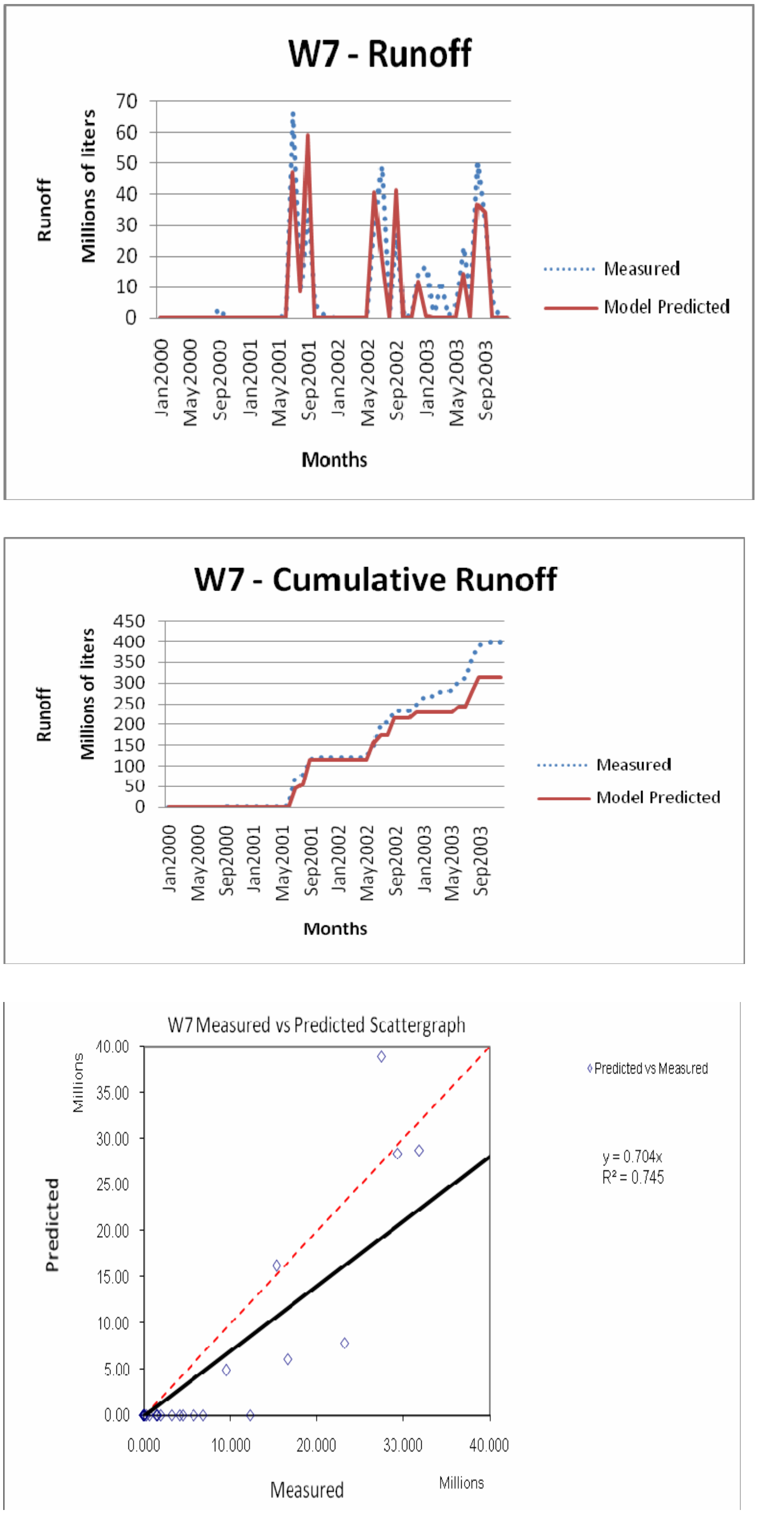
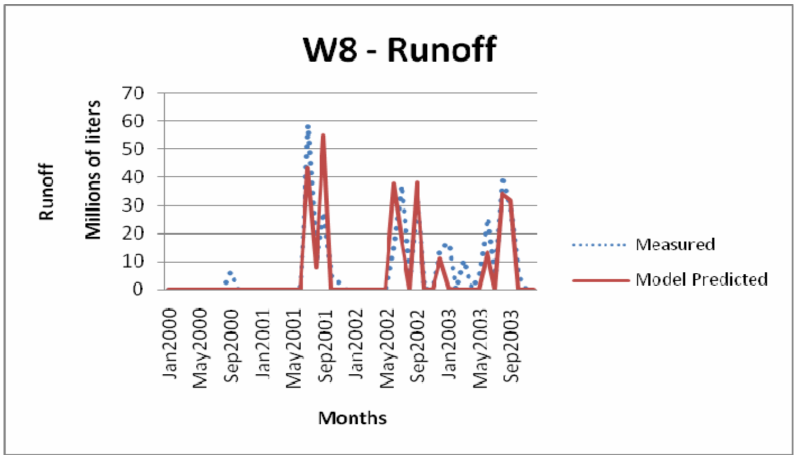
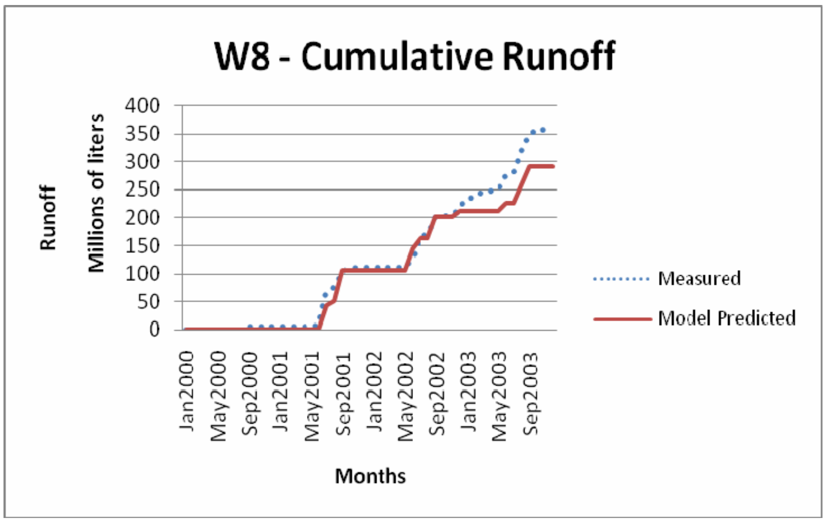


Figure A-15. A) Monthly runoff in the Winter7 pasture. B) Cumulative runoff in the Winter7 pasture. C) A measured vs predicted scattergraph for the Winter7 pasture runoffs





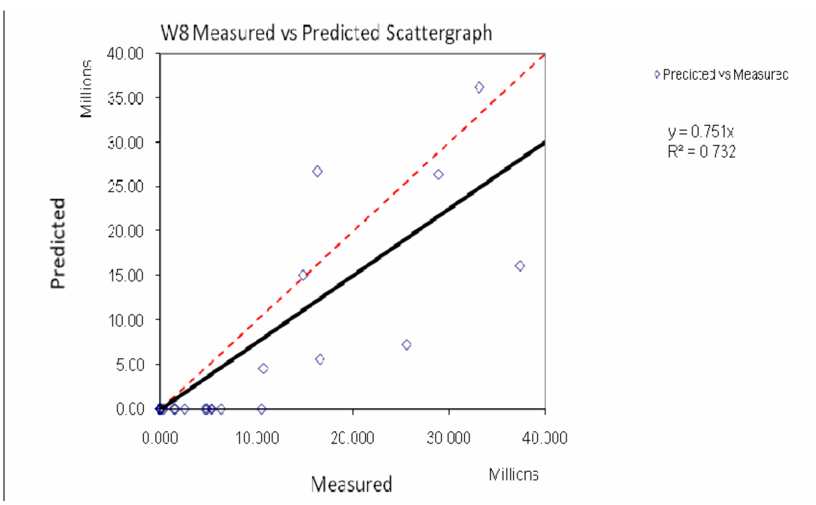
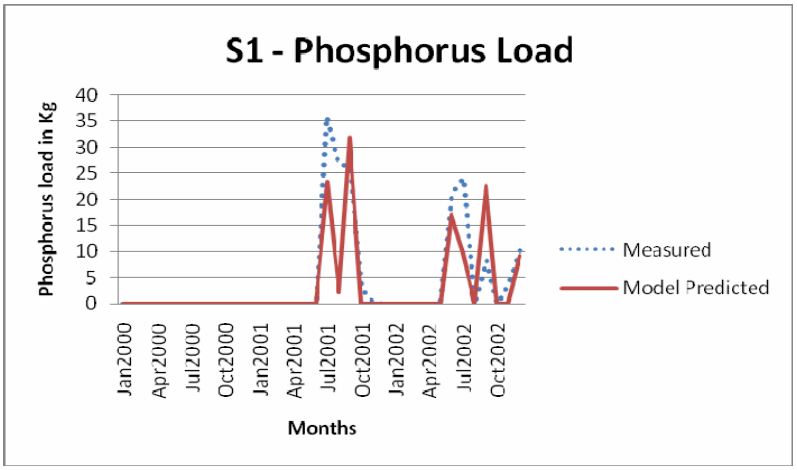
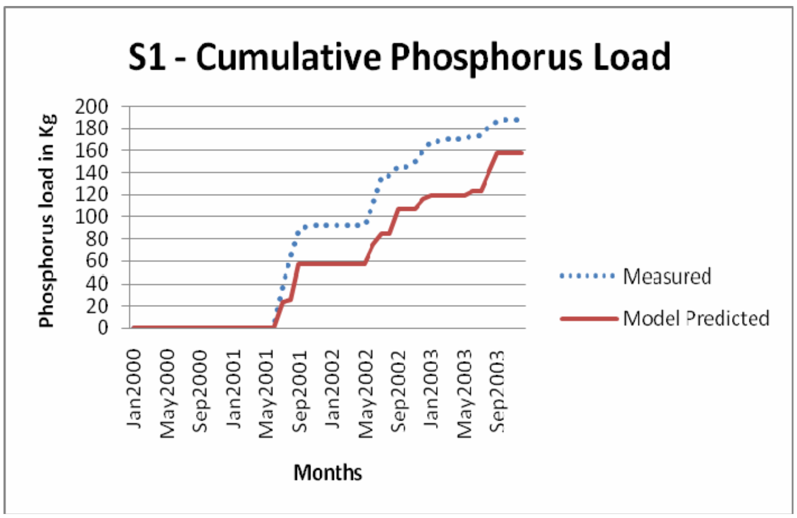


Figure A-16. A) Monthly runoff in the Winter8 pasture. B) Cumulative runoff in the Winter8 pasture. C) A measured vs predicted scattergraph for the Winter8 pasture runoffs





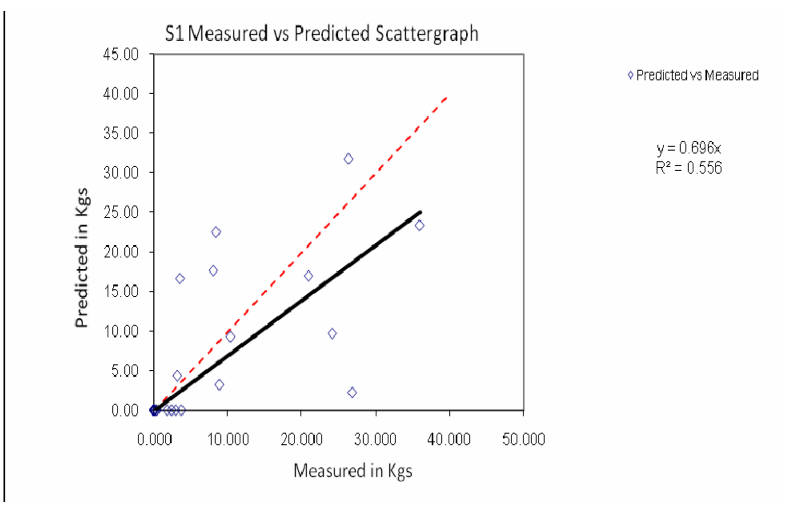
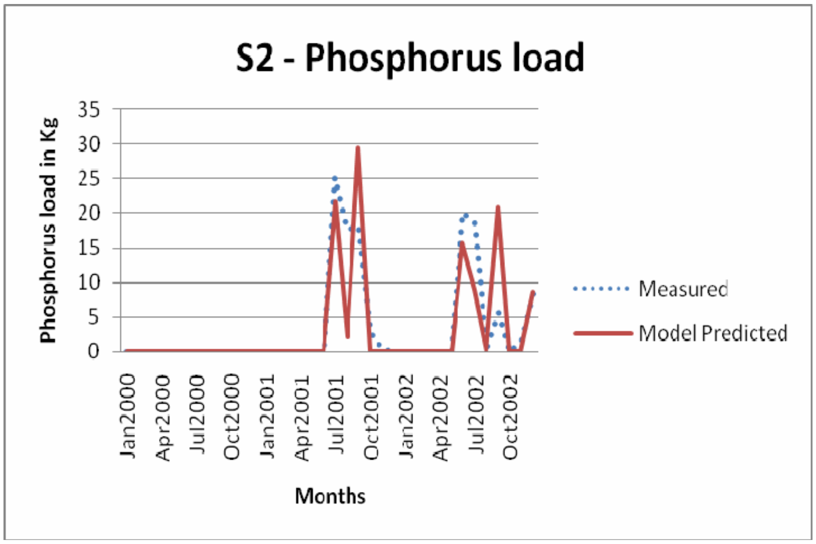
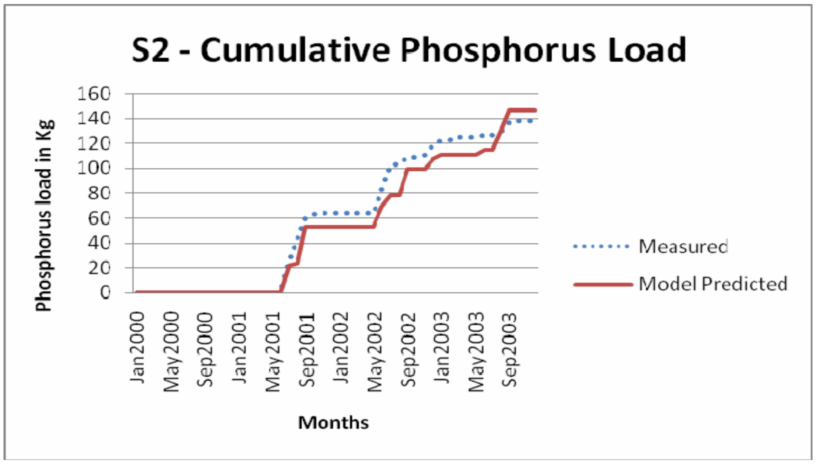


Figure A-17. A) Monthly phosphorus load in the Summer1 pasture. B) Cumulative phosphorus load in the Summer1 pasture. C) A measured vs predicted scattergraph for the Summer1 pasture Ph loads





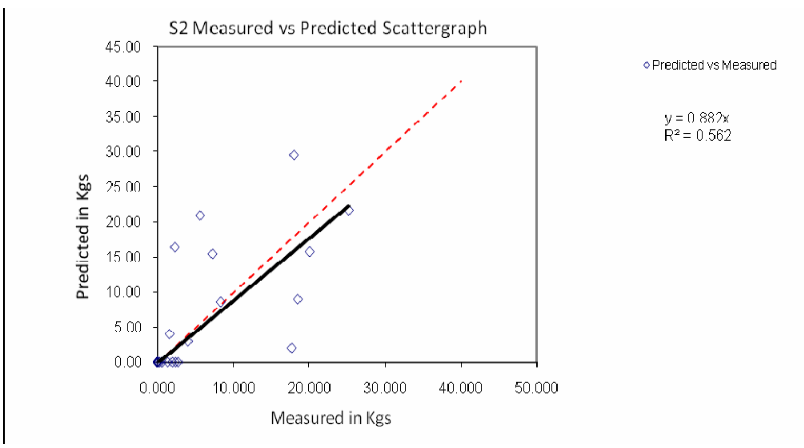
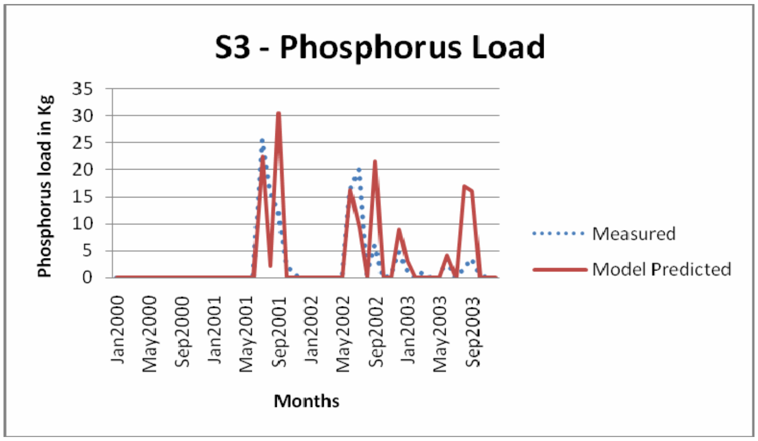
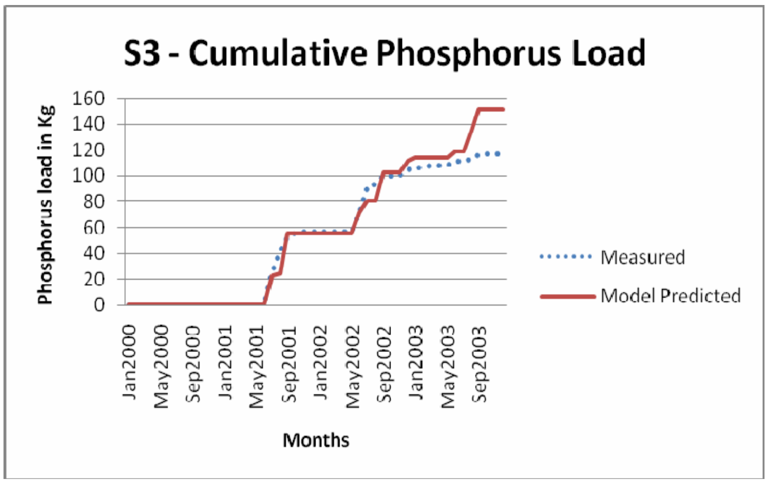


Figure A-18. A) Monthly phosphorus load in the Summer2 pasture. B) Cumulative phosphorus load in the Summer2 pasture. C) A measured vs predicted scattergraph for the Summer2 pasture Ph loads





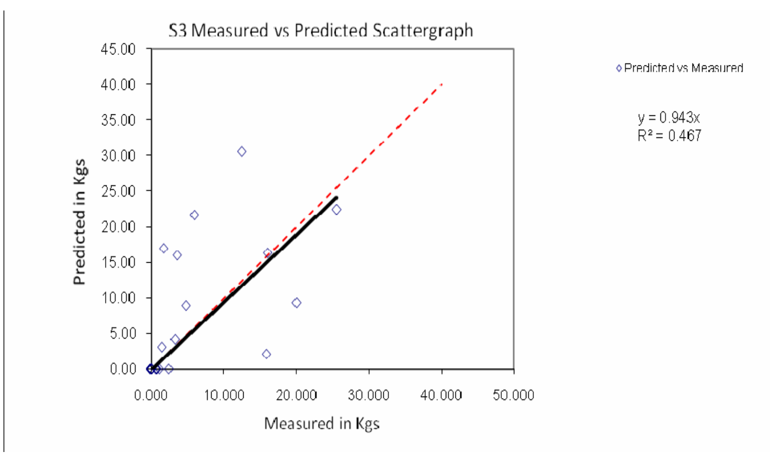
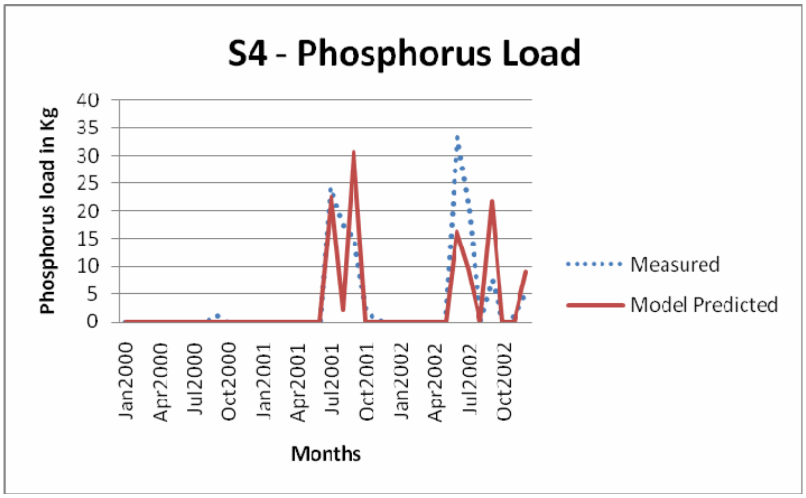
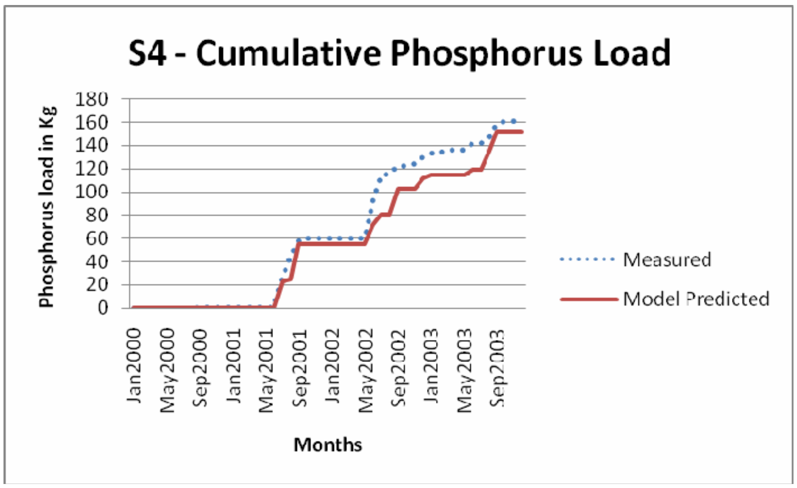


Figure A-19. A) Monthly phosphorus load in the Summer3 pasture. B) Cumulative phosphorus load in the Summer3 pasture. C) A measured vs predicted scattergraph for the Summer3 pasture Ph loads





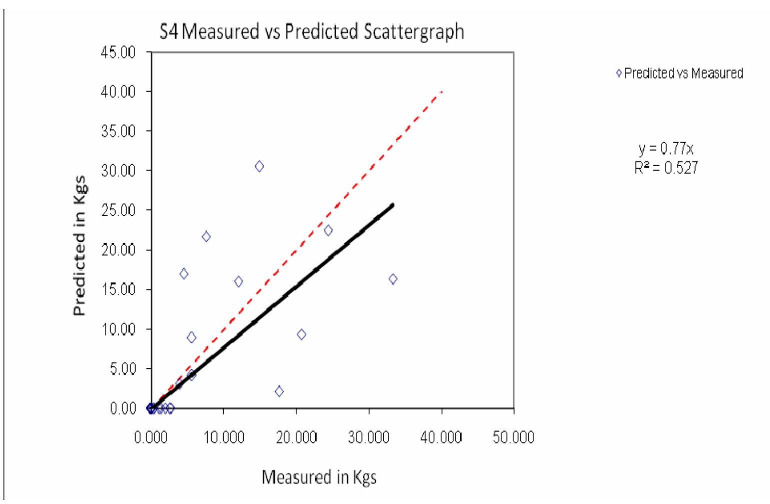


Figure A-20. A) Monthly phosphorus load in the Summer4 pasture. B) Cumulative phosphorus load in the Summer4 pasture. C) A measured vs predicted scattergraph for the Summer4 pasture Ph loads

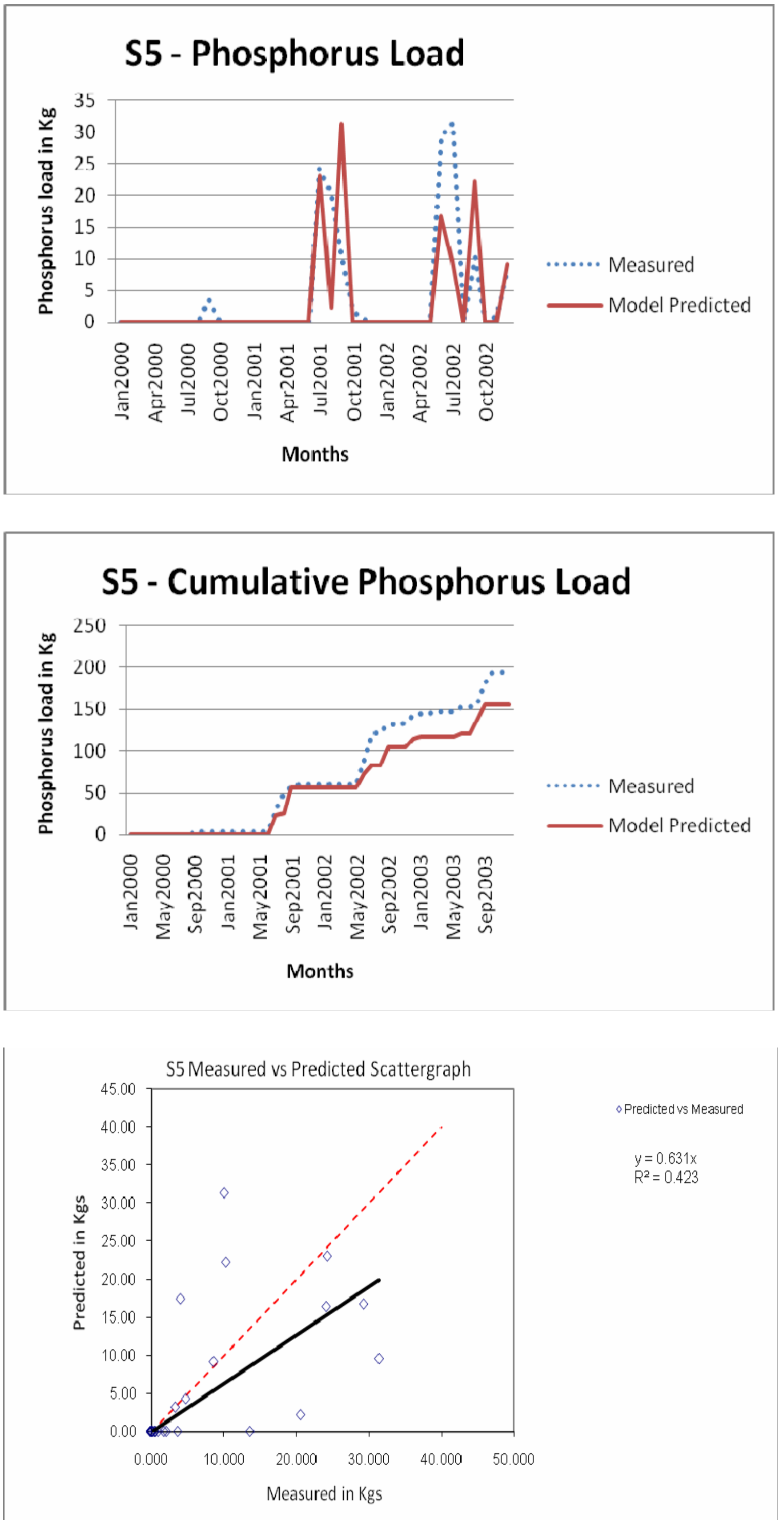


Figure A-21. A) Monthly phosphorus load in the Summer5 pasture. B) Cumulative phosphorus load in the Summer5 pasture. C) A measured vs predicted scattergraph for the Summer5 pasture Ph loads

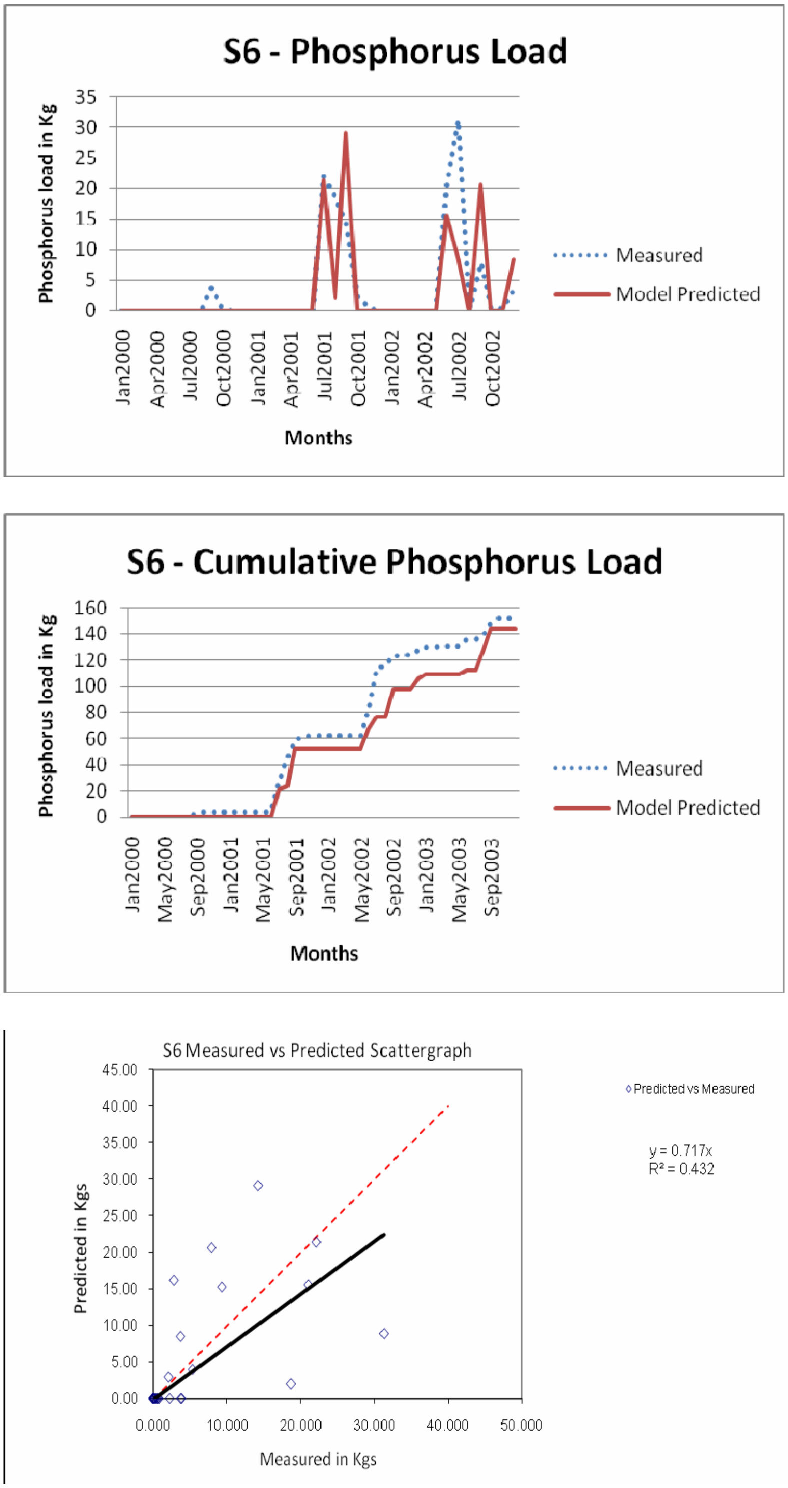


Figure A-22. A) Monthly phosphorus load in the Summer6 pasture. B) Cumulative phosphorus load in the Summer6 pasture. C) A measured vs predicted scattergraph for the Summer6 pasture Ph loads

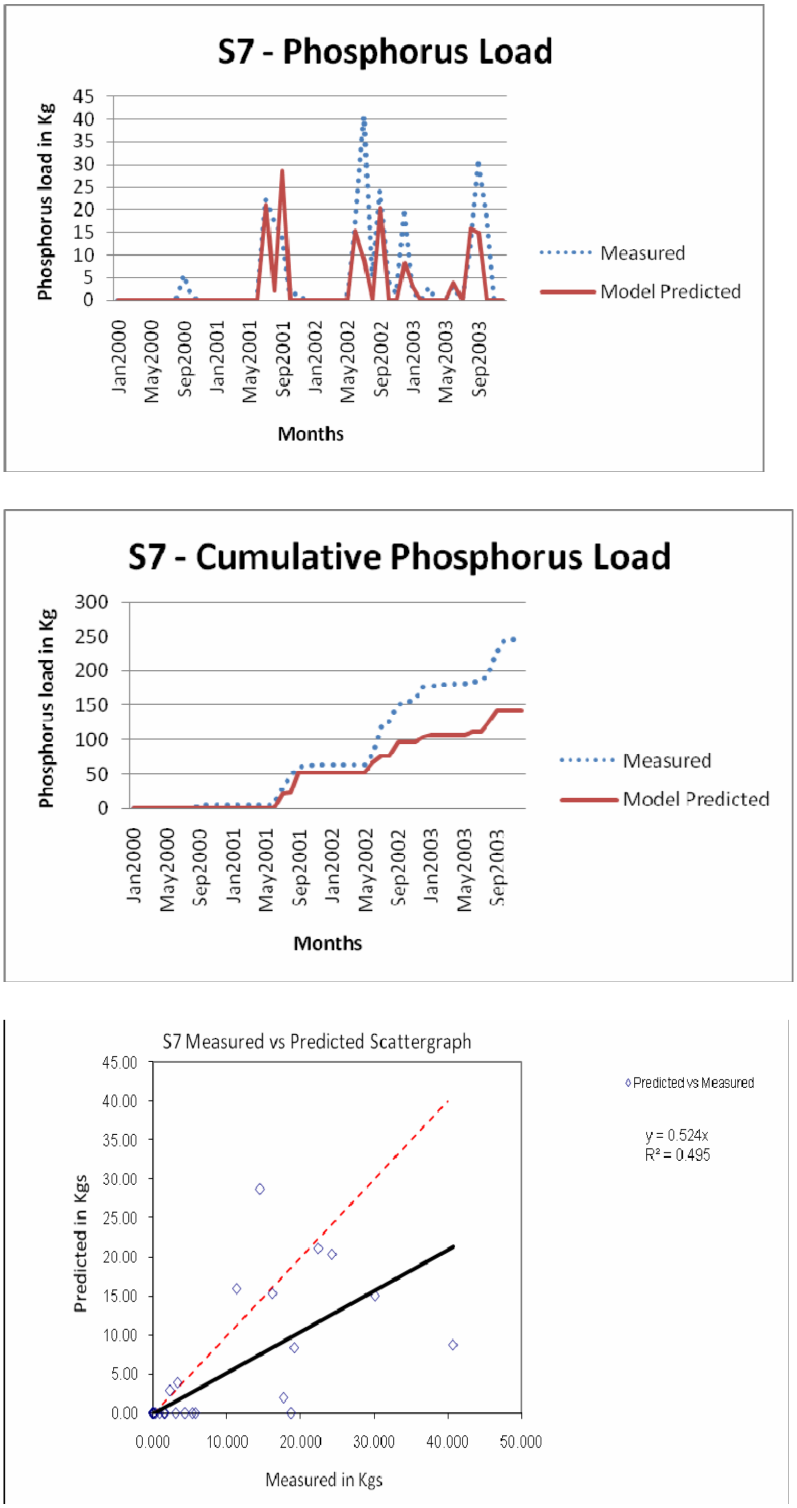
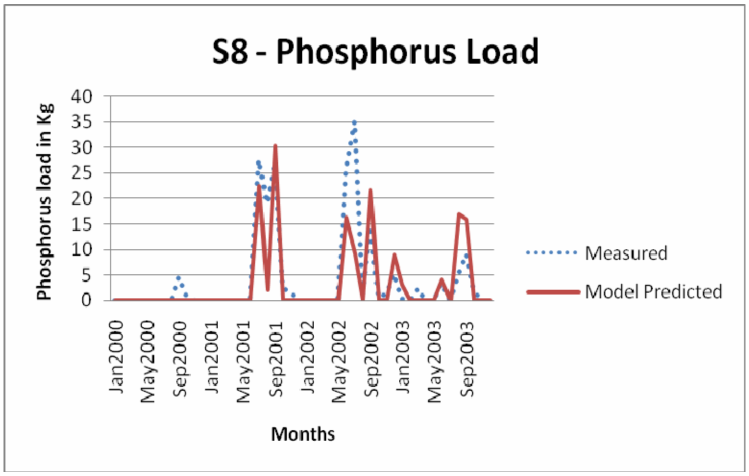
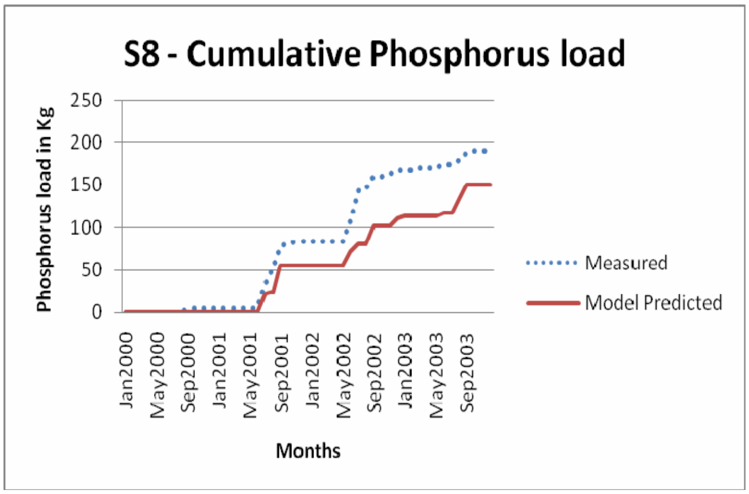


Figure A-23. A) Monthly phosphorus load in the Summer7 pasture. B) Cumulative phosphorus load in the Summer7 pasture. C) A measured vs predicted scattergraph for the Summer7 pasture Ph loads





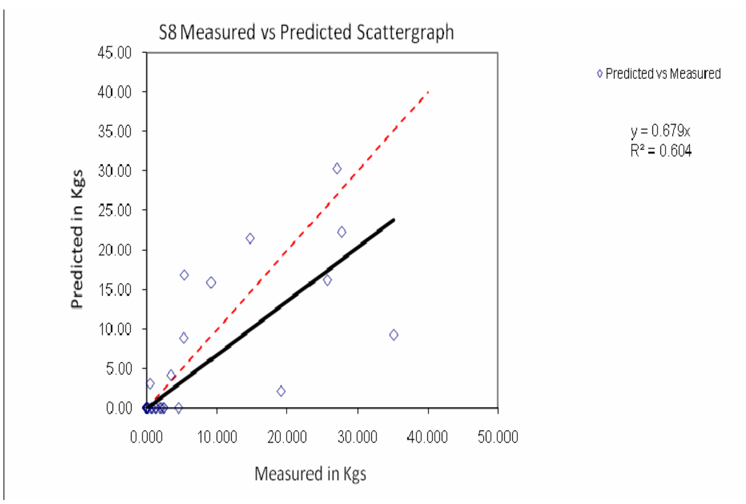


Figure A-24. A) Monthly phosphorus load in the Summer8 pasture. B) Cumulative phosphorus load in the Summer8 pasture. C) A measured vs predicted scattergraph for the Summer8 pasture Ph loads

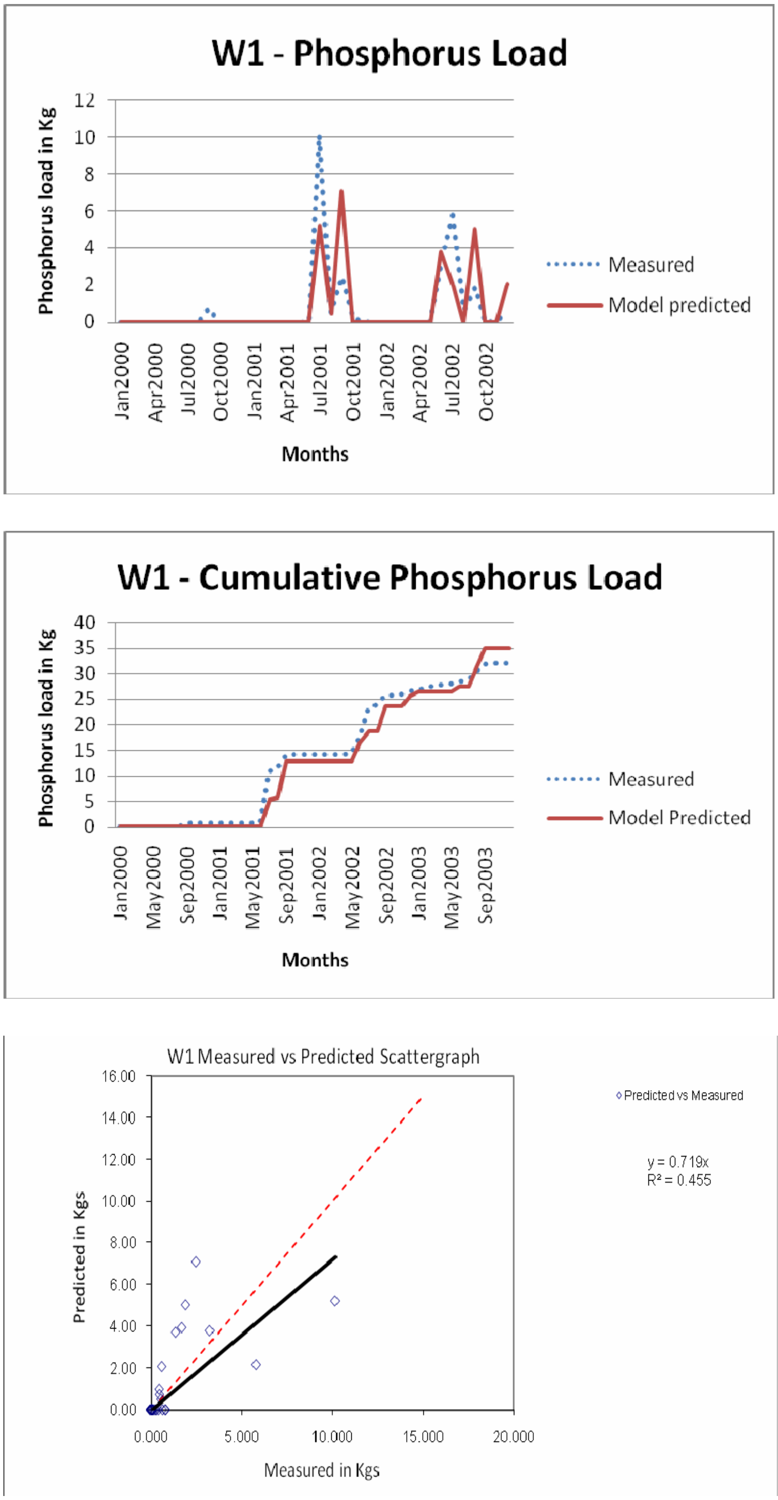
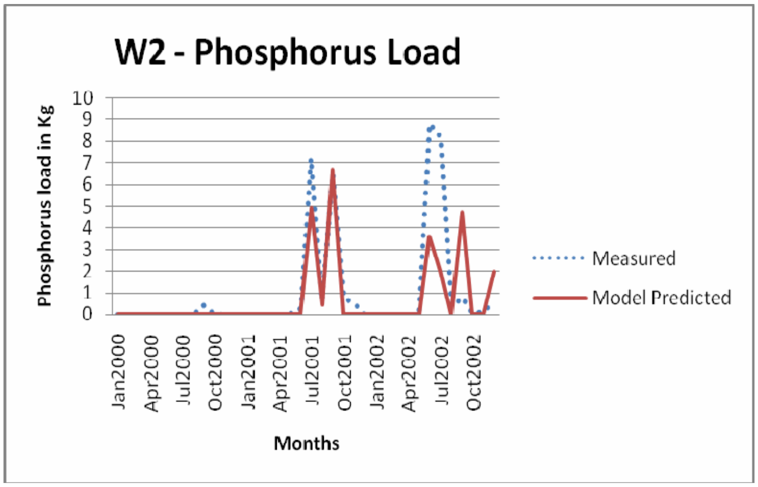
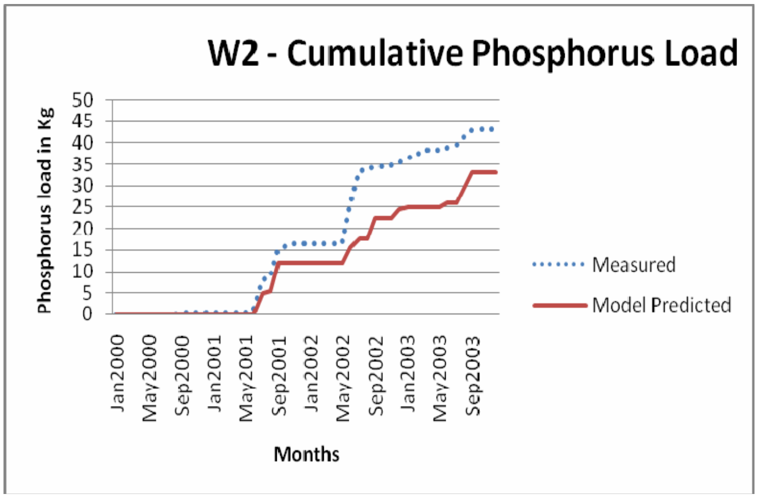


Figure A-25. A) Monthly phosphorus load in the Winter1 pasture. B) Cumulative phosphorus load in the Winter1 pasture. C) A measured vs predicted scattergraph for the Winter1 pasture Ph loads





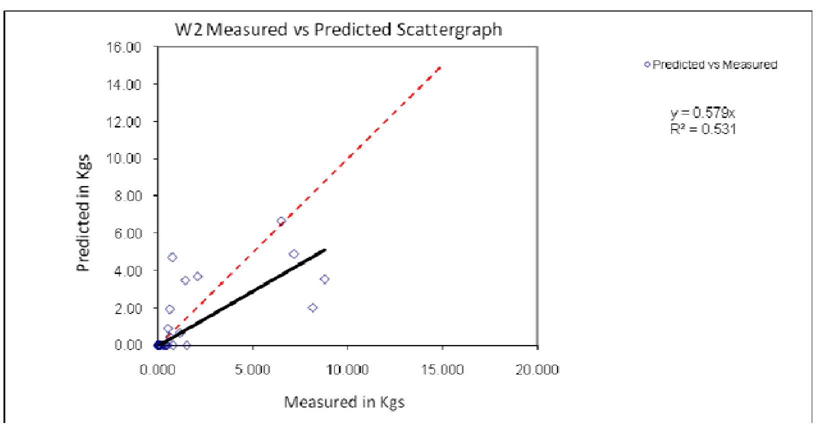
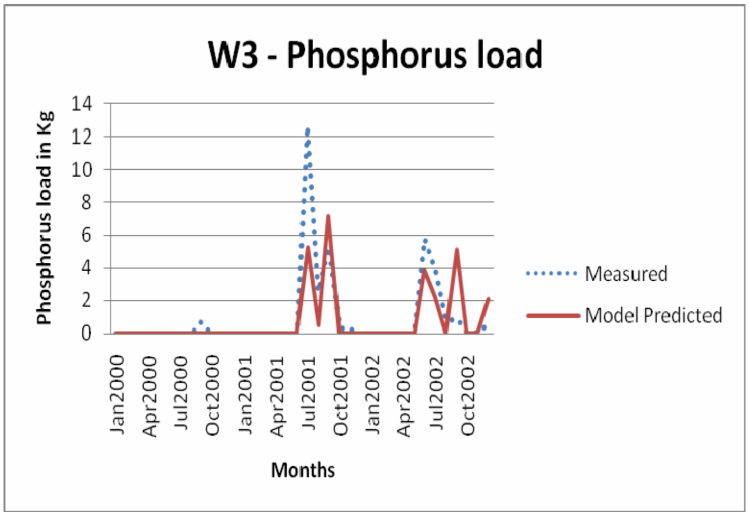
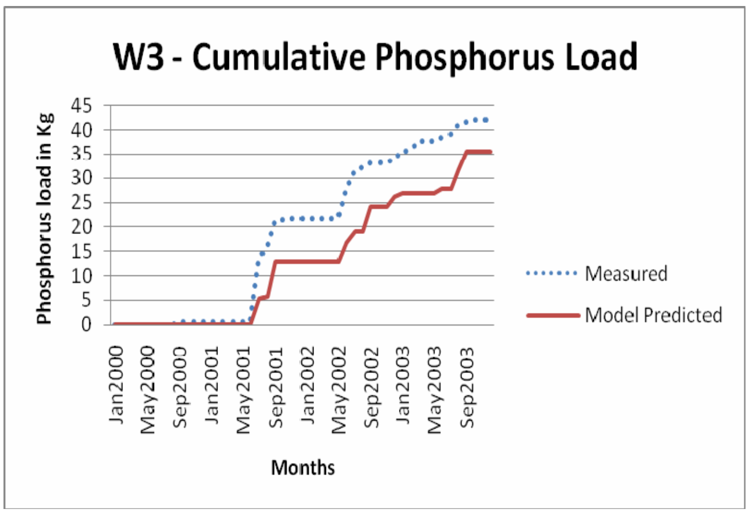


Figure A-26. A) Monthly phosphorus load in the Winter2 pasture. B) Cumulative phosphorus load in the Winter2 pasture. C) A measured vs predicted scattergraph for the Winter2 pasture Ph loads





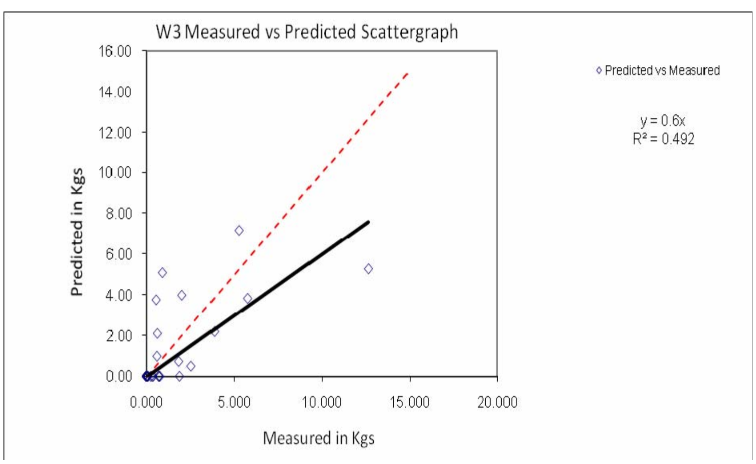


Figure A-27. A) Monthly phosphorus load in the Winter3 pasture. B) Cumulative phosphorus load in the Winter3 pasture. C) A measured vs predicted scattergraph for the Winter3 pasture Ph loads

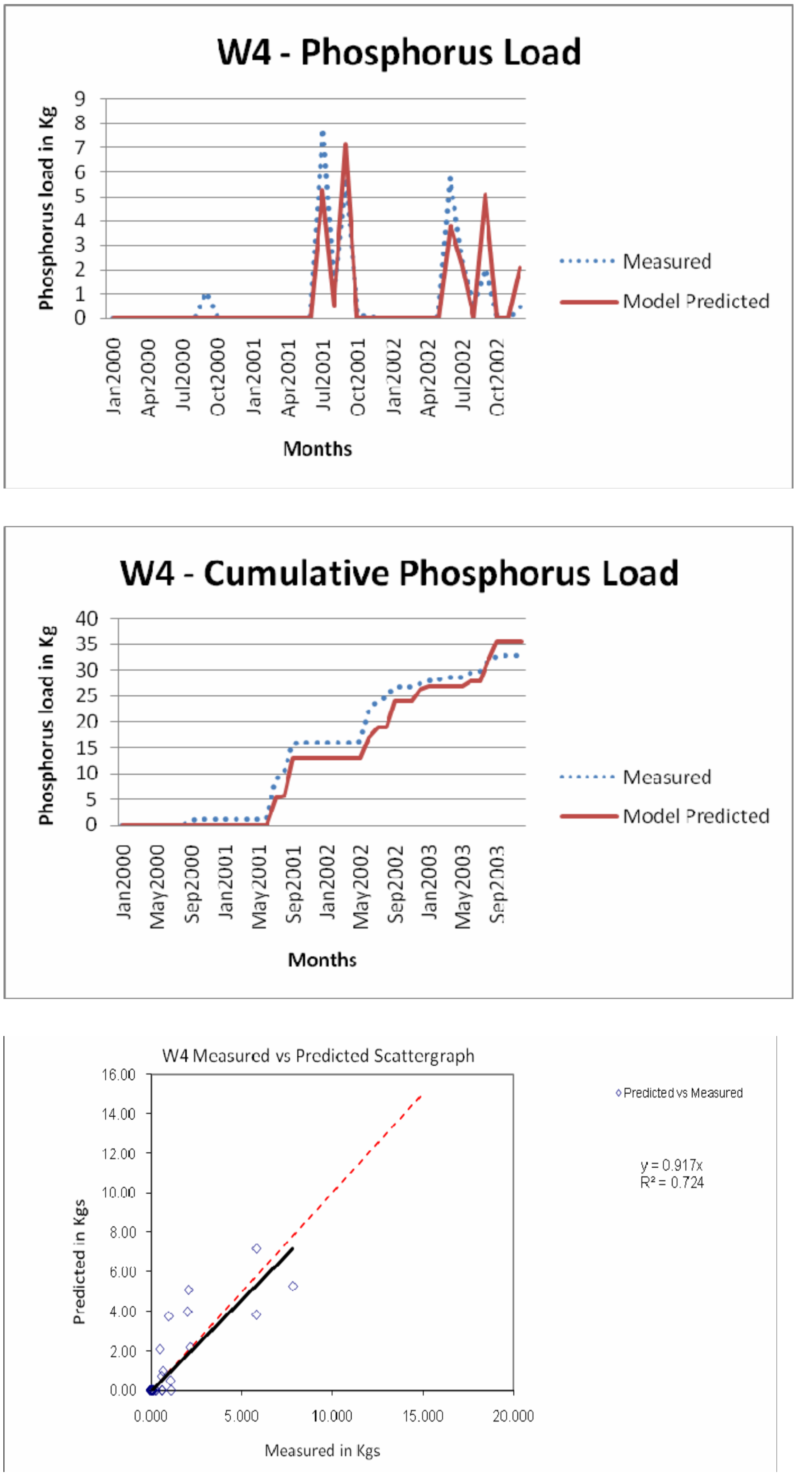


Figure A-28. A) Monthly phosphorus load in the Winter4 pasture. B) Cumulative phosphorus load in the Winter4 pasture. C) A measured vs predicted scattergraph for the Winter4 pasture Ph loads

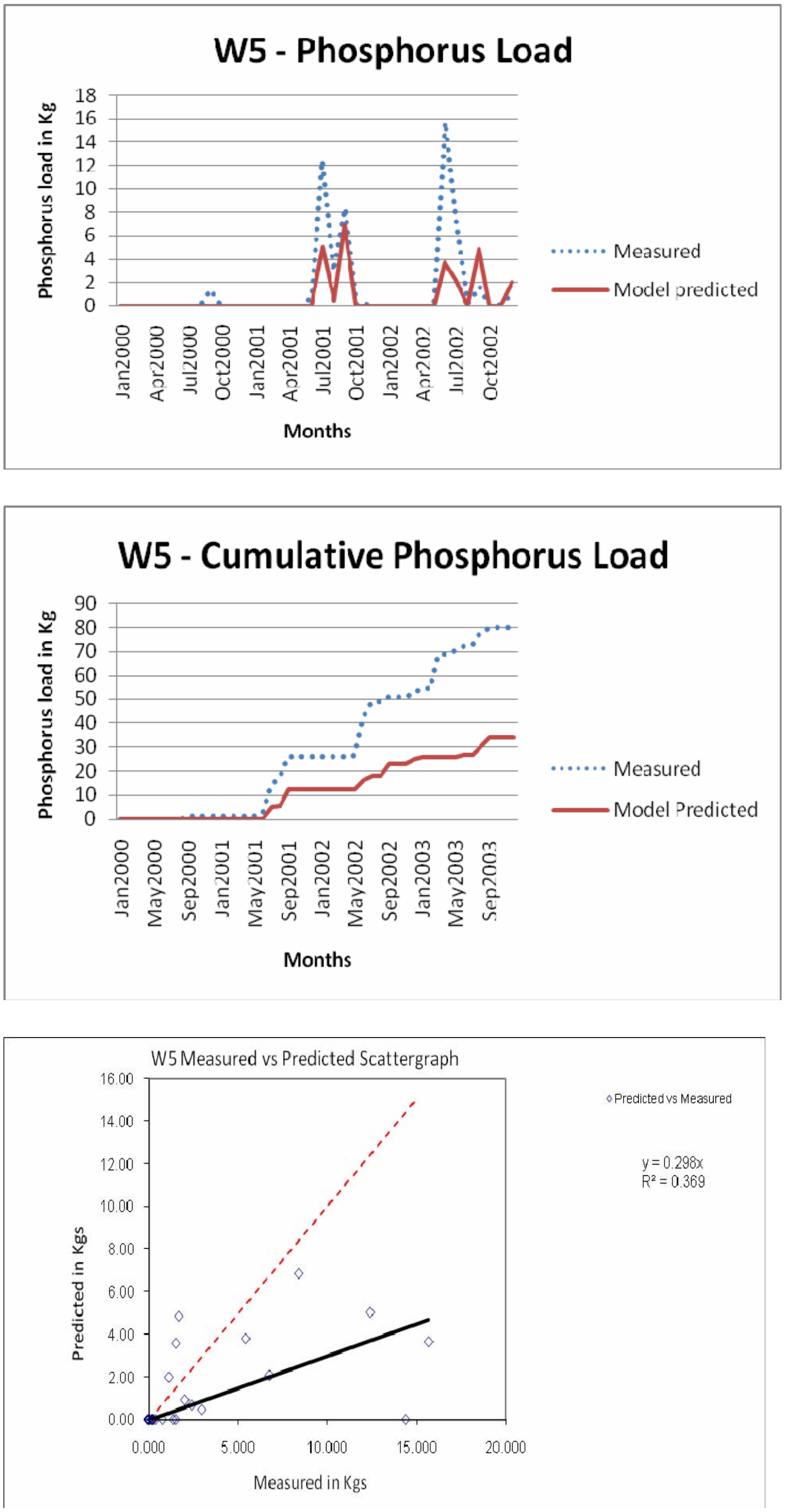
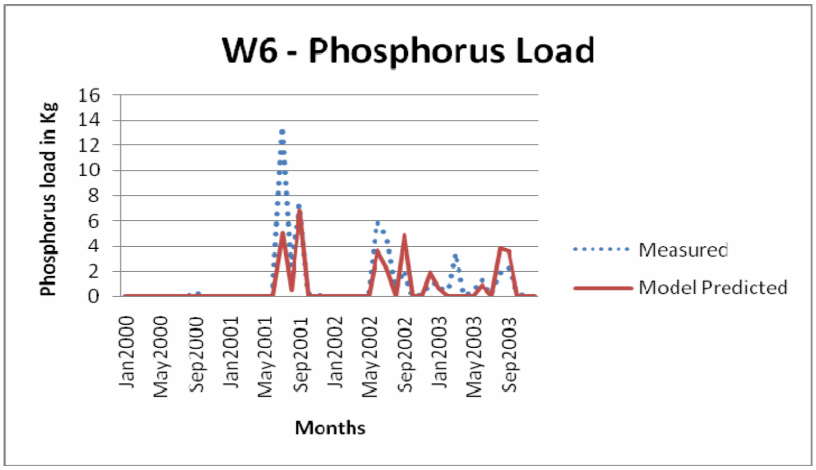
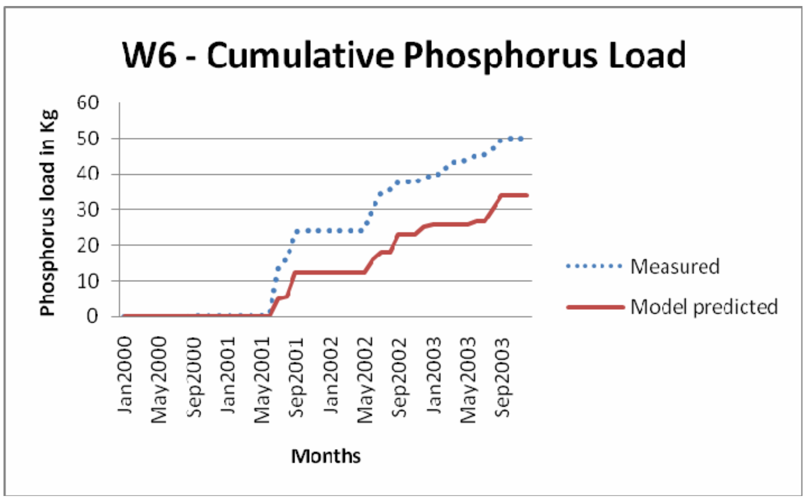


Figure A-29. A) Monthly phosphorus load in the Winter5 pasture. B) Cumulative phosphorus load in the Winter5 pasture. C) A measured vs predicted scattergraph for the Winter5 pasture Ph loads





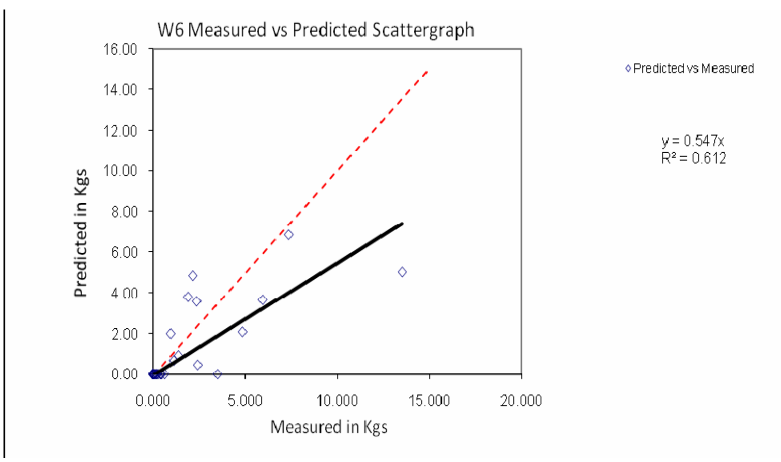


Figure A-30. A) Monthly phosphorus load in the Winter6 pasture. B) Cumulative phosphorus load in the Winter6 pasture. C)A measured vs predicted scattergraph for the Winter6 pasture Ph loads

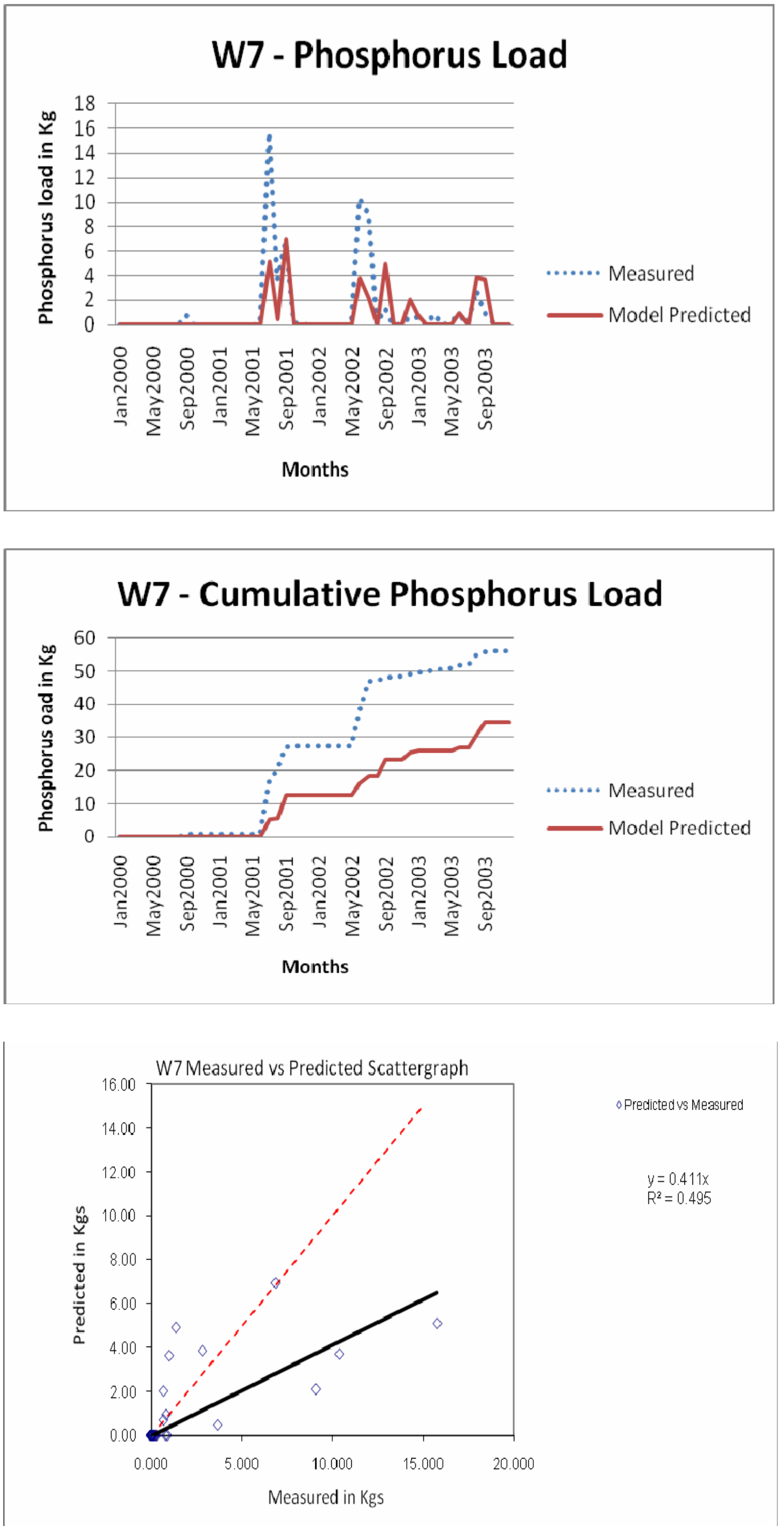
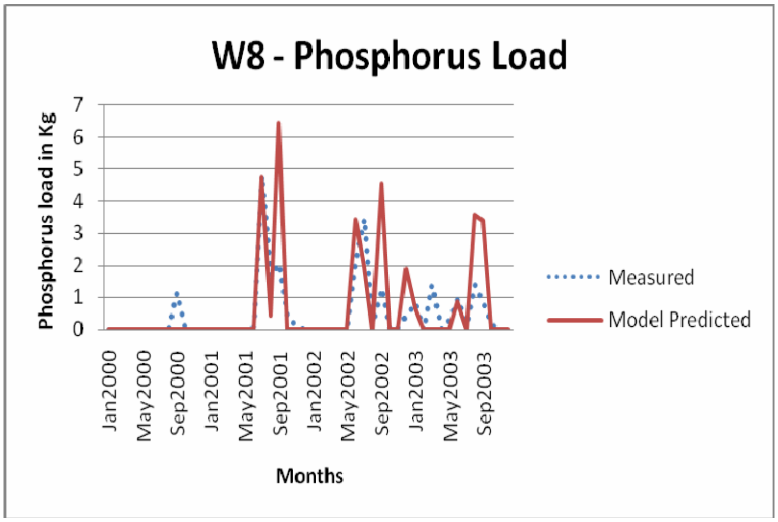
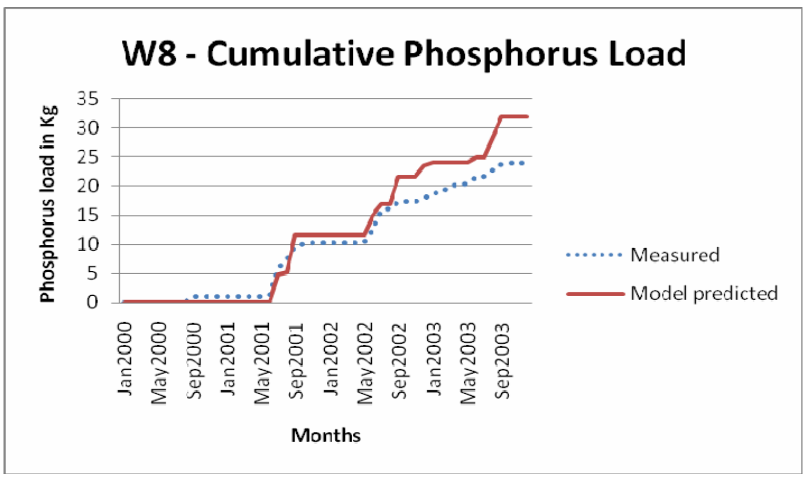


Figure A-31. A) Monthly phosphorus load in the Winter7 pasture. B) Cumulative phosphorus load in the Winter7 pasture. C)A measured vs predicted scattergraph for the Winter7 pasture Ph loads





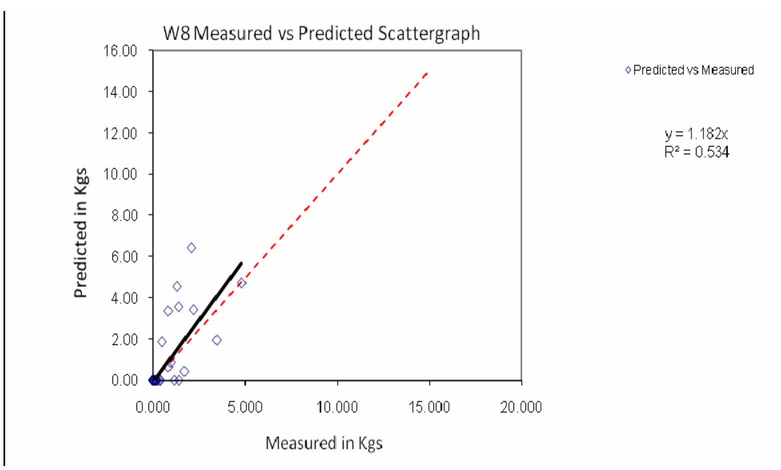


Figure A-32. A) Monthly phosphorus load in the Winter8 pasture. B) Cumulative phosphorus load in the Winter8 pasture. C)A measured vs predicted scattergraph for the Winter8 pasture Ph loads

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BIOGRAPHICAL SKETCH

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