ASSESSING WATER AVAILABILITY IN THE OROUA RIVER CATCHMENT

A thesis presented in partial fulfillment of the requirements for a Master Degree in Applied Science (Agricultural Engineering)

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ABSTRACT

The study estimated the 1993-1998 natural flows as well as their corresponding reliabilities along Kiwitea Stream and Oroua River upstream of the old Kawa Wool station. These estimates could present a baseline condition for assessing the hydrologic capability of the catchment for the existing rights and the amount of streamflow still available for additional rights.

The study demonstrated that water availability modeling could be a useful tool in water resource management and planning for the Oroua catchment. The "usual" or high river flow allocation management for the Oroua River wherein a right may abstract water up to its permitted rates could be modeled in WRAP. The results of the simulation based on full abstraction of permitted rates suggested that on a monthly basis, there was enough flow physically available to meet all consented abstraction rights including the minimum flow requirement at Almadale and Spur Road stations throughout the 1993-1998 simulation period.

The study had identified an apparent shortcoming of the WRAP model in simulating the MWRC's water allocation schemes at times of low river flow wherein water rights are either restricted or curtailed whenever the flow reached the set monthly flow threshold and the minimum flow level. The WRAP program was lacking of a mechanism or algorithm that will allow a water diversion target to vary depending on a gauged flow at other locations.

The study demonstrated that the criteria stipulated in the Oroua Catchment Water Allocation Regional Plan for rostering abstraction at times of low river flow could be accounted in WRAP water availability modeling using a weighted ranked priority scheme. The results of simulation apportioning the combined maximum abstraction rates for irrigation purposes, based on prior use and natural upstream-to-downstream location among irrigation rights, indicated a minimal increase in the utilization of available water of the Oroua River. Thus, with increased water use as a management objective, such options would not be an attractive alternative.

To facilitate relevant hydrologic and institutional water availability and reliability assessment of the Oroua River, it is recommended that a modification be made in the WRAP program to include mechanism or algorithms that will allow automatic change of diversion target as a function of gauged flow. Also, a shorter computational interval, such as weekly or daily, would yield more relevant results for real-time water management for the Oroua River.

For future simulation or modeling studies for the Oroua River, there is a need to have an actual streamflow measurement or gauging station downstream of the river for validation purposes. There is also a need to have data on actual abstractions and discharges to the Oroua River and its tributaries.

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CHAPTER I
INTRODUCTION

1.1 The Global Scenario

Water issues have been on the international agenda for the past 35 years at least, and in recent years, became the focus of growing international concern and debate. (Abu-Zeid and Ken Lum, 1997). The issues stem from the rapidly growing demand for freshwater due to the increase in world population during the twentieth century. In the last 50 years, the global demand for freshwater for human consumption has increased over fourfold while world population roughly doubled in the same period. Water for irrigation and industrial production is the major component of this increase, but the demand for water in municipal areas is also increasing particularly in countries undergoing rapid urbanization. During the same period, there has been a dramatic increase in water pollution as a result of the combined wastes produced through industrialization, urbanization, and intensification of agriculture (Abu-Zeid and Ken Lum, 1997).

A world water crisis is expected to emerge during the 21st century as the demand for water is accelerated by a continuously growing population, increasing per capita use for domestic purposes, and mounting needs of agriculture and industry (Postel, 1992). It is estimated that by year 2030, the global demand for food will have increased by 60% of present food requirements. The growing reliance on irrigation, the biggest user of water (accounting for about 69% of all withdrawals worldwide) to increase crop production, will mean withdrawing more water from finite and already strained resources (FAO, 2000). Moreover, recognition of the need for water in the preservation or improvement of the environment and the maintenance of wildlife habitats for aesthetic and recreational uses has been growing in recent years.

The increasing demand from all water sectors, including the environment, against a limited supply has intensified competition for access to water (Geyer-Allely, 1998; Molden and Sakthivadivel, 1999; Abdel-Dayem, 2000). Water pollutants in concentrations that render the water unusable for subsequent uses further limit the downstream freshwater supply (Keller, et. al., 1996; Seckler, 1996; Geyer-Allely, 1998; FAO, 2000). Competition among agriculture, industry, and cities is further complicated by other broad social objectives such as equity in access to water and food security (Molden and Sakthivadivel, 1999).

In an environment of growing scarcity, competition, and concern over the quality of water available for extractive and environmental uses, resource management naturally shifted away from the goal of capturing more water towards that of designing demand- and user-focused approaches aimed at improving water use efficiency in management (Winpenny, 1995; Seckler, 1996). Nowadays, many countries are recognizing, and acting on, the need for an integrated water resources management approach, which considers both supply and demand side pressures, targets the total water cycle, includes environmental sustainability as a key consideration, and aims to minimize waste, maximize water use efficiency, maximize water availability, optimize water allocation to competing users including the environment, and limit access to sustainable levels (Geyer-Allely, 1998).

To date, a considerable number of strategies have been formulated and proposed to address the challenge of meeting demand in a sustainable way while minimizing conflicts among users. General strategies identified include four principal directions: increasing output per unit of extracted water; reducing losses of usable water to sinks; reducing water pollution; and reallocation of water from low-valued to high-valued uses. These four areas contain the set of opportunities for increasing water productivity (Seckler, 1996) which is seen as a logical approach to address the pressing need to increase food production even as the freshwater share of the agriculture sector is declining in favor of the municipal and industry sectors (FAO, 2000). Limiting water quality degradation and promoting re-use of water, especially for agriculture, are seen as ways of maximizing water availability. In this regard, the potential of alternative water sources like industrial effluent re-use, greywater, and storm water use is also being explored (Geyer-Allely, 1998).

Economic instruments are considered key tools to moving towards sustainable water resource management (Geyer-Allely, 1998). In an effort to reverse trends of overconsumption and rising pollution, among others, the 1992 International Conference on Water and the Environment in Dublin produced a guiding principle stating that water has an economic value in all its competing uses and should be treated as an economic good (Rodda, 1995 as cited by Wall, 1997; Perry, et. al., 1997; Geyer-Allely, 1998). It was believed that failure in the past to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. Managing water as an economic good is seen as an important way of achieving efficient and equitable use and of encouraging conservation and protection of water resources. Reforms in water pricing regimes are taking place in some countries to remove cross subsidies and reflect the cost of water use (Geyer-Allely, 1998).

Water institutions or those that espouse formal as well as informal water law, water policy, and water administration are undergoing remarkable changes worldwide. This stems from the inherent limitations of the existing institutions in dealing effectively with the new set of problems that are not related to resource development but to resource allocation and management. The old development paradigm pivoted on centralized decision-making, administrative regulation, and bureaucratic allocation is fading fast to pave the way for a new paradigm rooted in decentralized allocation, economic instruments, and stakeholder participation. As the notion of water provision as a public good and welfare activity is giving place to the concept of water as an economic good and input in economic activity, cost recovery and financial viability concerns are being reflected increasingly at the policy level. Allocation and conflict resolution mechanisms are being created or strengthened in both the legal and policy spheres. Recognizing that water is both a public and an economic good, water allocation schemes are attempting to combine economic efficiency and equity objectives. Water users, who were customers or clients in the surplus era of water development, have now become important players in the scarcity era of the water sector. Increasing the role of user organizations, non-government agencies, women, environment, and other self-help groups is now being considered in water administration and in the water sector decision process (Saleth and Dinar, 1999). Water resources policy development is changing in many countries, reflecting an evolution away from top-down planning processes with a selected number of powerful players, to a process more bottom-up in nature with a wider base of ownership and which addresses a broader range of issues (Geyer-Allely, 1998).

1.2 New Zealand Scenario

New Zealand is well-endowed with freshwater compared to many countries. It is estimated that the country has an annual water resource of 300,000 million cubic metres. Although abundant, the availability of this resource is not uniformly distributed over the country at any one time (Statistical NZ, 1993; Waugh, 1992). Prevailing westerly winds blowing across the ocean bring abundant precipitation, especially on the western sides of both islands, but rainfall decreases as one moves east. The eastern areas of both islands normally have dry summers and suffer seasonal soil moisture deficits, and problems of access to water supplies can become pronounced (Waugh, 1992; Memon, 2000). On a nationwide and annual basis, the intensity of water use at 0.6 percent of available resources, is among the lowest in the OECD (OECD, 1996 as cited by Memon, 2000). Nevertheless, local or seasonal competition for water exists and total demand exceeds supply at times in many catchments.

Components of the demand are quite diverse, variable, and include primary and secondary industry, urban and rural water supply, fishing, irrigation, electricity generation, wildlife, effluent disposal, and recreational and cultural values (Sharp, 1991 as cited by Memon, 2000). Conflicts in water allocation are between competing demands for extractive uses of water such as domestic, industrial, hydro-electric generation, irrigation, stock water supply and forestry and for instream uses such as recreation and conservation. These conflicts not only reflect the underlying difficulties of managing water as a common property resource: those of non-excludability (i.e. control of access of potential users) and subtractability (i.e. each additional user is capable of subtracting from the welfare of others), but in many respects, manifest the changing demand and usage patterns and progressive shifts in New Zealand's environmental value systems. Until recently, allocation of water for hydro-electricity generation was considered a national development priority by central government and given precedence above all other uses. At the regional level, municipal water supply and farming needs were traditionally accorded priority by the catchment boards. Progressively, the needs of other activities such as conservation, horticulture and forestry have received recognition in response to increasing diversification of the New Zealand economy and society (Memon, 2000).

The challenge to improve water quality is probably the biggest hurdle in promoting sustainable resource management in the country. Seeking acceptable means to protect and enhance water quality is arguably the single most important activity of regional councils (Memon, 2000). Notwithstanding the overall superior quality of New Zealand water resources compared with those of many other countries, water pollution in the country is alarmingly high when seen in relation to the relatively small size of its current population of 3.8 million people.

New Zealand's major water resources have been extensively developed for irrigation, hydro-electricity generation, and water supply (Mosley, 1990; Waugh, 1992). In 1980s, there began a general move away from engineering solutions to water shortage problems and flood protection to a more conservative approach of matching demand with availability, emphasizing efficiency of water use, and keeping people away from flood waters (Fenemor, 1992). The emphasis has shifted towards more careful management of a resource for which demand is steadily growing, and which must be allocated amongst competing alternative uses (Mosley, 1990).

New Zealand's experience in integrated water management goes back to the 1940s (Ward and Scarf, 1993 as cited by Memon, 2000). The so-called 'catchment control plans' for soil conservation and river control have been carried out since the 1960s, while basin-wide water resource inventories and informal water allocation plans have been made since the late 1970s. Water quality issues became an additional component of such plans in the 1980s. The institutional arrangements for water resource management in New Zealand have been radically recast since then. These reforms encompass substantive changes to the philosophy and objectives of water resource management and formalize a number of past practices within a decentralized planning framework for sustainable resource management (Memon, 2000). At present, water allocation is identified as a high priority in the Ministry for the Environment's Draft National Agenda for Sustainable Water Management (Robb, 2000).

New Zealand is internationally acknowledged for having successfully adopted the quota management system for fisheries (Memon and Cullen, 1990 as cited by Memon, 2000). There is a continuing interest on the part of the government to make wider use of economic tools for resource management at the regional and local level. A number of urban communities are considering options to encourage water conservation. Some options are adopting user-pays charging methods and turning local government water supply companies into corporate and private. The regional councils, who are responsible for all matters of water use and allocation among others, have for the moment come out decidedly in favor of allocation procedures based on consultation and political compromise rather than allocation by market competition. At the moment, only a few councils have seriously considered market-based allocation regimes. These include the trial establishment of a transferable water permit regime in the Waimea groundwater system (Tasman District) and the investigation for such a regime for the Wairau groundwater system (Malborough District). So far the most forthright attempt in this direction has been made by MWRC in its plan for the Oroua Catchment. This plan builds on the agreement between the Council and major water permit holders in this catchment to apportion, restrict or suspend water abstractions at times of low flows and allows for transfer of permits between irrigators within the catchment (Memon, 2000).

1.3 Problem Statement

An adequate supply of quality water is a necessary condition for population and economic growth (Chan, 1995). As populations and economies grow and as countries encounter the limits of their water supplies, competition for finite water resources will intensify and so will conflicts among water users (Winpenny, 1995; Abdel-Dayem, 2000).

With growing population and limited water resources, there is an increasing need, worldwide, to manage water resources better. This is especially true when all or most of the water resources in a basin are allocated to various uses. Effective strategies for obtaining higher productivity while maintaining or improving the environment must be formulated. Effective allocation procedures that minimize and help resolve conflicts must be developed and implemented (Molden, 1997; Molden and Sakthivadivel, 1999).

With the growing scarcity of water and increasing competition for water across sectors, economic issues in water allocation are increasing in importance in river basin management (McKinney, et. al., 1999). A number of countries are reforming traditional systems for allocating shares of finite water resources. They are moving away from historical allocations based on land titles or administrative appropriations that have been unable to successfully address growing pressures from increasing demand (Geyer-Allely, 1998).

The allocation of water resources in river basins is a complex and critical issue (Geyer-Allely, 1998; McKinney, et. al., 1999). The sustainability of future economic growth and environmental health depends on it. Successful resource management and allocation requires knowledge of the occurrence, quality, and variability of water resources as well as the demands on the water resources and the community's aspirations for its management (Fenemor, 1992). An optimal allocation process must begin with the recognition of the interdependence and legitimate claims of all water users, including the environment. Clear entitlements, in terms of ownership, volume, reliability, transferability, and quality also depend on a sound knowledge of water resources and use patterns (Geyer-Allely, 1998). Water right systems allocating limited resources to numerous users are becoming increasingly important as population and economic growth result in demands exceeding supplies (Wurbs, 2000).

However, river basins are inherently complex systems with many interdependent components (McKinney, et. al., 1999). Streamflow and other hydrologic variables are characterized by great variability and randomness. Water availability and reliability depend on institutional considerations, as well as on interactions between multiple types of use and numerous water users with complex systems of reservoir or other facilities and river basin hydrology. Numerous water users share the same resources and affect one other. Moreover, water management decisions necessarily require qualitative judgement in determining acceptable levels of reliability for various situations. Since beneficial use of water is based on ensuring a high level of reliability, particularly for municipal supplies, trade-offs occur between the amount of water to commit for beneficial use and the level of reliability that can be achieved (Wurbs, 2001). In general, however, the present understanding of the human impact on hydrologic cycles and the water needs of the environment has serious gaps (Geyer-Allely, 1998).

In view of the above mentioned scenario, efficient comprehensive analytical tools such as water availability models are needed to make the rational water allocation decisions necessary to achieve sustainable water use strategies for many basins (McKinney, et. al., 1999). One water availability model, which could be used to simulate surface water management and possibly identify better management strategies, is the Water Rights

Analysis Package (WRAP). WRAP is a generalized model for simulating river basin management within the framework of a priority-based water allocation system. The model is designed to facilitate the assessment of hydrologic and institutional water availability and reliability for existing and proposed water rights. It could be used to evaluate water supply capabilities associated with alternative water resources development and management plans, water use scenarios, demand management strategies, regulatory requirements, and reservoir system operating procedures (Wurbs, 2000).

1.4 Objectives

The main goal of the study is to apply the Water Rights Analysis Package to the Oroua River Basin to assess its hydrologic and institutional water availability and reliability. Specifically, the study aimed to achieve the following objectives:

1. To evaluate the utility of the WRAP model as a method of assessing hydrologic and institutional water availability and reliability in the Oroua River Basin.
2. To document the naturalized and unallocated streamflows under existing water rights, as well as the frequency, and volume and period reliabilities for supplying those rights.
3. To present alternative demand management scenarios.

1.5 Outline of the Study

The study began with understanding the current water management and allocation practice for the Oroua River Catchment. Global and New Zealand scenarios on water supply vis-à-vis demand, water resources management and allocation, and water-related issues are presented in Chapter 1. Literature relating to water resources management, water availability modeling, and water allocation methods and criteria is reviewed in Chapter 2. Chapter 3 discusses the methodology used in the study and provides the rationale for the selection of WRAP, including an outline of WRAP simulation. Chapter 4 presents and discusses the results of the water availability modeling in accordance with the set objectives. Conclusions derived from the study as well as recommendations and areas of further research for the application of the water availability model in the Oroua Catchment are documented in Chapter 5.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Introduction

There has been substantial effort to address the water resource issues that revolve no longer around water development and quantity but around water allocation and quality. Significant changes have been made in an effort to address growing water scarcity, improve water use and productivity, resolve conflicts among uses, and protect the resources on technical, institutional, and economic grounds.

This chapter summarizes the literature on water resources management, focusing mainly on water availability modeling and water allocation. It reviews the different approaches for estimating naturalized streamflow at gauged and ungauged locations, GIS application in streamflow estimation, water availability models, and numerical criteria to assess model accuracy and performances. It also provides background information on the major water allocation mechanisms, outlines the economic principles of scarce resource allocation in the context of water resources, and enumerates some criteria for allocation.

2.2 Water Availability

Adequate assessment of the quantity and quality of available water is fundamental to the successful management and to the rational and sustainable use of water resources (Milorado and Marjanovic, 1998). Available water may be defined as the total amount of water flowing into a water balance domain from precipitation, surface and subsurface sources plus any change in storage, less the amount of water set aside for committed and non-utilizable outflow. It represents the amount of water available to a service or use (Molden, 1997; Molden and Sakthivadivel, 1999).

Equally important for effective water resources planning and management are river/reservoir system reliability studies. However, water availability and reliability is affected by institutional considerations such as water rights and interactions between multiple types of use, numerous water users with complex systems of reservoirs and other facilities, and river basin hydrology (Wurbs, 2001). Further, the quantity of water that can be managed and controlled is not equivalent to quantity available for use, since some water must always remain in water bodies to support aquatic life as well as recreation, landscape, and cultural values.

Water availability could be evaluated from the perspectives of: 1) reliabilities in satisfying existing and proposed water use requirements; 2) effects on the reliabilities of other water rights in the basin; 3) instream flows; and 4) unallocated flows available for additional water rights applicants (Wurbs, 2000).

2.3 Water Resources Management Balance versus Water Balance

A water balance remains one of the basic tools for the quantitative assessment of water resources, their formation, and behavior in the region or watershed (Molnar, et. al., 1988). A water balance approach is based on the conservation of mass, that is, the sum of inflows must equal the sum of outflows plus any change in storage (Molden, 1997; Molden and Sakthivadivel, 1999). The water balance equation may be expressed as,

$$Inflow = Outflow \pm \Delta\ Storage \qquad (2\text{-}1)$$

The water balance of a catchment is a deterministic relationship between the water balance components that are random variables in time and space, with usually unknown probability distributions. The independent variable is rainfall, which is transformed in the hydrologic system into the dependent output variables evaporation, streamflow, and change in soil storage (Everson, 2001).

Milorado and Marjanovic (1998) made a distinction between water resources management balance (WRMB) and a water balance or water budget. They pointed out that a WRMB accounts for multiple use of a given volume of water in the calculation, while a simple water balance does not. In doing so, it is possible to satisfy the demand for water even when the natural water balance does not make it possible. This approach causes planners and decision-makers to look at a much wider scope of alternatives to meet demand. The process also reinforces the role of water quality in water resources assessment.

2.4 Water Resources Management Modeling at the River Basin Scale

The river basin has been acknowledged to be the appropriate unit of analysis for integrated water resources management (McKinney, et. al., 1999). It is at this level that hydrologic, agronomic, and economic relationships can be integrated into a comprehensive modeling framework. Modeling at this scale can provide essential information for policymakers in their decisions on allocation of resources.

The river basin system is made up of three components: 1) source components such as surface water and aquifers; 2) demand components off-stream like irrigation, industries, and municipals, plus demand components in-stream such as hydropower, recreation, and environment; and 3) intermediate components like treatment and recycling facilities. It is characterized not only by natural and physical processes but also by physical projects and management policies. The essential relations between components and the interrelations among them in the river basin can be considered in an integrated modeling framework (McKinney, et. al., 1999).

McKinney and co-authors (1999) cited simulation and optimization as the two principal approaches to river basin modeling. In the simulation approach, models mimic water resources behavior based on set rules (hypothetical or actual) governing water allocations and infrastructure operations. Models for the optimization approach optimize allocation based on an objective function and accompanying constraints. Model classification under each approach is shown in Figure 2-1.

A distinguishing advantage of simulation models, as opposed to optimization models, is their ability to assess performances over a period of reliable forecasts for flows and demands. Consequently, simulation is the preferred technique to assess water resources system responses to extreme nonequilibrium conditions like drought. Thus, it is also the favored method to identify the system components most prone to failure, or to evaluate system performance relative to a set of criteria over a long period such as climate change and changing priority demands like accelerated municipal growth.

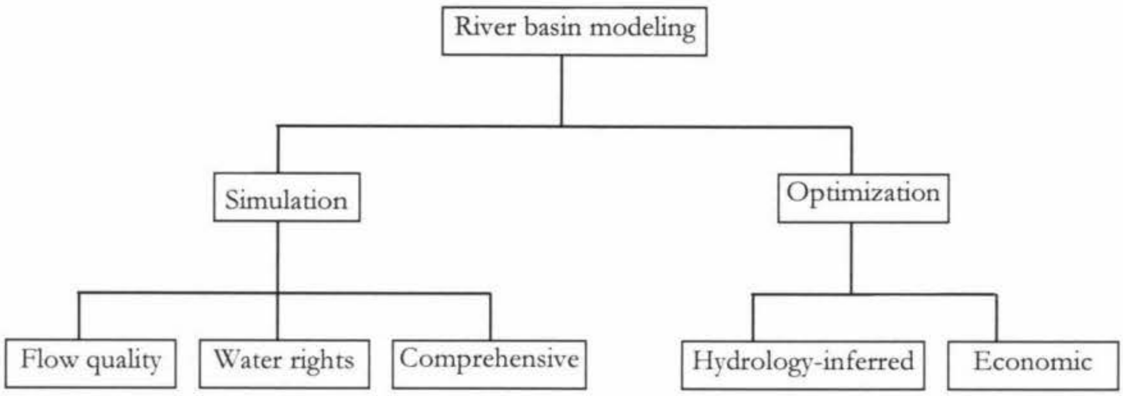


Figure 2-1. Approaches to River Basin Modeling

Optimization models have a simulation component, though often rudimentary, to characterize the hydrologic regime and constituent mass balances. Thus, they are usually referred to as integrated simulation and optimization models. Their main advantage over simulation models is their ability to incorporate social value systems in the allocation of water resources. In the hydrology-inferred approach, the objective functions for intra-sectoral allocation are derived from hydrologic specifications. The economic optimization model uses an objective function based on economic criteria of optimal water allocation. Other criteria used include equity or environmental quality. Though a wide range of optimization models has been developed, most of them focused on only one or few water users.

Combined hydrologic and economic models are best equipped to assess water management and policy issues at the river basin level (Young, 1995 as cited by McKinney, et. al., 1999).

2.5 Hydrologic Modeling

Hydrologic modeling can be viewed as a means to get useful information about a watershed. Hydrologic models are developed to predict certain elements in the management and utilization of water resources (McCuen and Snyder, 1986). Streamflow has been the primary element of interest (McCuen and Snyder, 1986; Milorado and Marjanovic, 1998).

Hydrologic models are best defined rigorously in relation to the concept of a system. McCuen and Snyder (1986) used the following definition of Dinkin (1970):

> System: A system may be considered to be an ordered assembly of interconnected elements that transform, in a given time reference, certain measurable inputs into measurable outputs. Inputs and outputs are usually represented as functions of time. These functions may be continuous or discrete.
>
> Models: Models are simplified systems that are used to represent real-life systems and may be substitutes of the real systems for certain purposes. The models express formalized concepts of the real systems.

In general, there are two purposes for hydrologic models: 1) to illustrate a complex system in a simplified and readily comprehended manner, as well as test the hypotheses about processes and systems; and 2) to predict the behavior of the system (Black, 1996; Watts, 1997).

2.5.1 Types of Hydrologic Models

Hydrologic models have been classified or categorized based on a number of ways such as modeling approach, structure, complexity of formulation, and spatial representation. Consequently, one model would fall under more than one type depending on the classification used. Below are some of the types of models cited in the literature.

Based on modeling approach. As cited by McCuen and Snyder (1986) from Decoursey (1971), Snyder (1971), and Woolhiser (1971), three approaches to modeling are conventionally recognized. They are the stochastic, deterministic, and parametric approaches. The stochastic approach uses the simplest concepts of watershed processes whose outputs are thought of as a time series of random events. The physical basis of the stochastic elements is implicit, with some properties of the time series like mean values and variabilities deriving their magnitude from the watershed in which the stochastic generating processes are at work. The essence of the stochastic process is the nonpredictability of exact magnitudes of each element of the series. At the opposite end of stochastic models are the deterministic models whose generating process contains no random components. In deterministic models, at a given value of initial and boundary conditions, a set of inputs will always produce the same output values. Parametric models are compromise models in that they contain both stochastic and deterministic component processes. They start from the conceptualization of processes on the real watershed, and, through rigorous numerical techniques applied to observed inputs and outputs, attempts separation of the deterministic components. The deterministic components derived are associated with the predominant physical characteristics of the watershed.

Statistical hydrologic models evolved from the above three approaches to watershed modeling. They include any model built or modified to obtain optimum values of any of its elements through rigorous statistical procedures (McCuen and Snyder, 1986).

Based on model structure. In all aspects of hydrologic investigation, the three classically identified types of model structure include black-box models, conceptual models, and deterministic models (Anderson and Burt,1985). The black-box models contain no physically-based transfer function to relate input to output. Instead, they depend upon establishing a statistical correspondence between input and output. These models include a number of successful approaches like the unit hydrograph, extreme frequency analysis, regression analyses, and real time forecasting models. Such models may be highly successful with the range of data analyzed because the formal mathematical structure carries with it an implicit understanding of the underlying physical system. However, extrapolation beyond actual experience loses this physical "anchor", and the prediction then relies on mathematical technique alone. The inherent linearity of many black-box models casts doubt on the worth of extrapolation. On the other end, deterministic models are based on complex physical theory making them data extensive, time consuming, and costly to develop and operate. By offering a totally physically-based approach, they also offer the ability to predict the complete runoff regime and effect of catchment changes. An important aspect in the development of such models is their value in helping improve the present understanding of hydrologic systems.

Between the deterministic and black-box analyses are the conceptual models. Conceptual models are formulated on the basis of simple arrangement of a relatively small number of components, each of which is a simplified representation of one process element in the system being modeled.

Based on complexity of formulation. Based on their formulation, Watts (1997) cited the above models, in order of complexity, as empirical, conceptual, and physically-based models.

Empirical models are defined as concerned only with describing how the world behaves, with little attempt to explain the underlying physical principles. They are often developed intuitively, usually from an investigation of simple data sets. IHACRES (cited from Littlewood and Jakeman, 1994) is an empirical rainfall-runoff model that relates river flow to rainfall using the concept of the unit hydrograph. Physically-based models determine system behaviour based on physical process and measurable characteristics. The System Hydrologique Europeen (SHE) model developed over a 20-year period by cooperation between research institutions in France, Denmark, and the UK is considered one of the most complicated physically-based distributed models and also one of the most complete representations of the physical hydrologic cycle developed (cited from Abbott, 1986). Conceptual models are differentiated from physically-based models because their conceptualization is based on perceived system behavior rather than on physical processes. Some of the known conceptual hydrologic models include HYDrological Rainfall Runoff Model (HYDROM) produced by the UK Institute of Hydrology (cited from Blackie and Eeles, 1985) and the original Stanford Watershed Model (cited from Crawford and Linsley, 1965).

Based on spatial representation. Spatial scale of hydrologic models can vary within a wide range (Watts, 1997). Based on representing the spatial component of a hydrologic problem, models are classified as homogeneous or lumped, semi-distributed or semi-lumped, and heterogeneous or spatially-distributed.

Lumped models represent the whole hydrologic system as one homogeneous unit or "lump". They give no information about the spatial distribution of input or output variables but instead provide information about the average state of the system. They are robust tools providing a relatively straightforward means of modeling a response of large areas, especially if the output of a time series of values for the whole system is required.

Many conceptual catchment models are of this type, wherein the output is usually a time series of river flows at the downstream end of the catchment. One of the major difficulties with a lumped model is that only the main output can be verified. Without means to check the values of other time-variant components of the system, it is quite possible that the results are correct but that the mechanisms creating them are unrealistic. On the other hand, heterogeneous or spatially-distributed model formulations represent values of time-dependent variables at grid locations throughout a hydrologic system. They can be applied to any spatial scale from experimental plots to entire catchments where understanding the spatial influence of a change in time variant characteristics to the system is sought. Their common application is on investigating the impact of groundwater development (e.g., increased abstractions) or assessment of land use change in the catchment. Distributed models tend to be physically-based, implying that all parameters required to describe the system behavior have to be provided. They are usually time-consuming to set up and run, and require considerable computer resources.

As the names imply, semi-distributed or semi-lumped models lie between the lumped and distributed models. A typical catchment semi-distributed model represents the catchment by a series of lumped models predicting an average behavior over a number of small homogeneous units which are then aggregated and/or routed for a few predefined locations. Being basically lumped models, the semi-distributed models suffer from the main disadvantages of the former. They still represent the catchment by averages, though the spatial area represented is smaller, and offer little explanation of the actual processes. They require more calibration work than lumped models, but are far less data extensive than distributed models. One example of this model is the Great Ouse Resource Model (GORM) used in eastern England.

2.5.2 Time Scales in Hydrologic Modeling

Hydrologic models are rarely capable of producing output for a range of time scales within the simulation period. Most of them generate results that are distributed in time and are sometimes referred to as "temporally distributed model". They calculate the state of the system at pre-defined intervals called the time step. The choice of time steps may vary within each hydrologic simulation, depending on the rate of change in the system that needs to be represented adequately (Watts, 1997).

2.5.3 GIS Application in Hydrologic Modeling

A Geographic Information System (GIS) offers new opportunities for hydrologic modeling. It provides a framework for storing and manipulating large amounts of detailed spatial information derived from remote sensing, ground surveys, or interpolation of point measurements. As cited by Schumann and co-workers (2000), some GIS applications in hydrologic modeling includes:

- The use of GIS to improve the estimation of parameters in existing conceptual models such as in determining the composite runoff curve number for a drainage basin with the widely used SCS model (Pilgrim and Cordery, 1992) from its land use data and digitized soil maps.
- Estimation of lumped catchment characteristics considering spatial heterogeneity of a catchment for parameterization of a lumped model.
- The use of distributed catchment characteristics as covariant mean to distribute a lumped state variable, as in the use of topographic index in the well-known TOP-model as a characteristic of the spatial variability of the soil water content (Beven, et. al., 1984)
- Subdivision of the catchment into so-called "hydrologic response units" (HRUs), which are similar with regard to selected characteristics and which are modeled separately, as in the precipitation-runoff modeling system (PRMS) of Leavesley and co-workers (1983).
- Subdivision of the catchment into equally-spaced square grid elements and representation of the hydrologic processes in these units by a parameter set in which the physical characteristics of the units are considered. An example is the SHE models (Abbott, et. al., 1986).

GIS has been employed in spatial water balance studies (Reed, et. al., 1997) and in conceptual rainfall-runoff models (TNRCC, 1997; Schumann, et. al., 2000). It has also been used to distribute streamflows from a gauged watershed to an ungauged subwatershed. In its evaluation of the different methodologies for calculating naturalized streamflows, the TNRCC (1997) recommended the traditional method combined with new tools to distribute flows using GIS-based unit-area runoff data.

2.6 Water Availability Modeling

Water availability modeling is an essential tool for effective water resources planning and management. It can be employed to determine the amount of unallocated water, prior to issuing a new water rights permit, to protect instream flows and flows to bays and estuaries (TNRCC, 1997; Wurbs, 2001).

Aside from river basin hydrology, water availability is affected by physical projects and management policies (McKinney, et. al., 1999). It is affected by institutional considerations and interactions between multiple types of use and numerous water users (Wurbs, 2001). To realistically simulate water allocation to different uses, the prevailing system of water rights in a basin must often be accounted for (McKinney, et. al., 1999). Some models that have been formulated especially to handle priority allocation based on water rights are the Texas A&M University's Water Rights Analysis Package (WRAP) and the Colorado River Institutional Model (CRIM).

CRIM is used to simulate and optimize water allocations under a variety of market and non-market arrangements and accounts for basin-wide priorities (Booker, 1995, as cited by McKinney et. al., 1999). It uses an interactive gaming simulation of the drought, where riparian states and the federal government are players. Games are played with rules based on existing compact agreements, a hypothetical interstate basin commission, and water markets.

WRAP simulates the management of the water resources of a river basin or multiple-basin region under a priority-based water allocation. Its typical simulation study involves assessing capabilities for meeting specified water management and use requirement during a hypothetical repetition of historical hydrology (Wurbs, 2000; 2001). Its conventional overall water availability modeling process for a river basin consists of two phases, namely: 1) developing sequences of monthly naturalized streamflows covering the hydrologic period-of-analysis at all pertinent locations; and 2) simulating the rights/reservoir/river system, given the input sequences of naturalized flows, to determine regulated and unallocated flows, storage, reliability indices, flow-frequency relationships and related information regarding water supply capabilities.

2.7 Watershed Characteristics Influencing Streamflow

The tremendous amount of work reported in the literature on the subject of watershed modeling provides insight into the relevance of various watershed characteristics in estimating streamflows (Wurbs and Sisson, 1999). The primary watershed characteristics governing streamflow may be outlined as follows:

a. Precipitation characteristics
b. Watershed area
c. Watershed characteristics affecting hydrologic abstractions and runoff volumes, such as land cover (land use and vegetation), soils, and antecedent moisture conditions
d. Topographic characteristics primarily affecting runoff response time, such as watershed shape and slope, stream tributary configuration, and stream channel slope
e. Watershed characteristics affecting subsurface base flow, such as soils, vegetation, soil moisture, channel bed materials, stream channel length, geology, and groundwater table

Watershed characteristics stated in items (c) and (e) govern the hydrologic processes that partition precipitation into streamflow and hydrologic losses such as surface storage, infiltration, soil moisture, and evapotranspiration.

2.8 Naturalized Flow

Naturalized streamflows represent flows in a river basin that would have historically occurred without the effect of human water development and use (TNRCC,1997; TNRCC, 1998; Wurbs, 2001). In a water permitting and regulatory context, they represent baseline conditions for the accounting procedures to determine unappropriated or unallocated flows, that is, flows at specific points which remain uncommitted after all existing water rights are satisfied both upstream or downstream of a location. In a planning context, they allow estimation of allocatable flow for temporary use, or after transfer of existing water rights, or upon the expectation that only some part of the permitted water will ever be demanded by existing water right holders. In other words, naturalized flows permit determination of the water available in the stream whether water were allocated to or used by certain users or not, thus enabling one to evaluate the effects of granting/changing/withdrawing water rights (TNRCC, 1997).

The relationship between naturalized flow, unappropriated or unallocated flow, and available expected flow concepts is:

$$NF = GF + D_h - RF_h + S_h + E_h \tag{2-2}$$

$$UF = NF - D_t - S_t - E_t - I \tag{2-3}$$

$$AF = NF - D_e - S - E - I + RF_e \tag{2-4}$$

where,

NF = naturalized flow
AF = available flow
D = diversions
E = evaporation
GF = gauged flows
UF = unappropriated flow
RF = return flows
S = storage change in a reservoir
I = instream flows and bay and estuary freshwater inflow reservations

The subscript h refers to the use of historical data, the subscript e refers to the use of forecasted or expected data, and t refers to theoretical diversions or authorized amounts.

Developing naturalized flows typically represents a major portion of the effort required for a water availability modeling study. It consists of three phases, as follows:

a. developing sequences of naturalized flows at stream gauging stations
b. extending record lengths and filling in gaps to develop complete sequences at all selected gauges covering the specified period-of-analysis
c. distributing naturalized flows from gauged to ungauged locations

2.8.1 Naturalized Streamflow Methodologies

The TNRCC (1997) reviewed and evaluated the different methodologies for calculating naturalized streamflows. The methodologies include the traditional approach, use of watershed runoff models, and a statistical method. They recommended the use of the traditional methodology for calculating naturalized streamflow, primarily because of its acceptability to stakeholders and its standardization. The three methods and the result of the evaluation are summarized below.

2.8.1.1 Traditional Method

In the traditional method, naturalized flows at gauging stations are determined by arithmetically adjusting gauged flows to remove the effects of human water use, which include diversions, return flows, and reservoir adjustments. This approach uses the general equation (equation 2.1) to calculate naturalized flows. The process of estimating naturalized flow consists of two major phases: 1) adjusting recorded streamflows and filling in missing records at existing locations for a pre-determined period-of-analysis of usually 40 years or more; and 2) distributing the naturalized streamflows estimated at gauging stations to ungauged sites. The step-by-step procedure is outlined below.

<u>Step 1:</u> Acquire raw data and complete missing value

The procedure begins with determining what gauged river flow information exists in the desired basin, at what locations, and what period-of-record (POR) is represented. Ideally, the desired POR should encompass enough of the historical record to be able to hydrologically depict the basin through what is believed to be the worst drought on record. All gauged flow data sets must be extrapolated to represent the entire POR at each of these selected gauges. Additionally, historical data on diversions, return flows, and evaporation rates of reservoirs must be acquired or estimated.

<u>Step 2:</u> Associate Each Water Right to a Gauge

The next step requires delineation of the drainage areas of all of the selected gauged locations. A base map is then produced with these delineated "major watersheds" for use in determining which critical points (water rights, outfalls, and reservoirs) are associated with which gauge. Each "major watershed" is subdivided into "subwatersheds" – one for each critical point. "Watersheds" refer to those areas associated with a gauge station, and "subwatersheds" are subunits of a watershed representing the drainage area of individual water rights. Then, each critical point is placed on the base map and its drainage area is delineated. These "subwatersheds" are numbered with respect to their relative downstream order within their "major watershed".

Step 3: Gauge Adjustments

The third step involves arithmetic adjustment of the gauged flows to remove the effects of human influence such as diversions, return flows, and reservoir adjustments. This produces a data set of naturalized streamflow.

Step 4: Distribution of Naturalized Streamflows from Gauged to Ungauged Watersheds

Finally, if desired, naturalized streamflows at each watershed, or control point, are then distributed to the subwatersheds within the watershed.

Since the traditional method uses observed data, the issues of adequacy, accuracy or reliability, and relevance of reported data confront it. Missing, inadequate, inaccurate, or simply unavailable data on streamflow, actual diversion, and reservoir adjustment computations are common problems. Estimation of return flows has been limited to the historical reported discharges of entities with water quality discharge permits.

2.8.1.2 Rainfall-Runoff Models

Rainfall-runoff models simulate hydrologic processes by converting precipitation to streamflow. Watershed runoff models may be used to simulate naturalized flows for situations wherein gauged streamflow, water use, and other data are lacking and when current and future watershed conditions are significantly different from historical conditions implicit to gauged flows (TNRCC, 1997).

The conventional approach for applying a model involves the following tasks (Wurbs and Sisson, 1999):

1. Sequences of recorded daily precipitation depths at all relevant precipitation gauging stations are provided as model input;
2. The river basin is divided into sub-basins to obtain flow at all pertinent locations. Initial values for the parameters are estimated for all sub-basins and stream routing reaches;
3. A calibration study is performed in which parameters are iteratively adjusted until the computed flows reasonably match the observed flows at stream gauging stations; and
4. The calibrated model is executed with given precipitation input to obtain sequences of daily flow at all pertinent locations. The daily flows are aggregated to obtain monthly flows.

2.8.1.3 Statistical Method

As cited by TNRCC (1997), the United States Geological Survey (USGS) has proposed a statistical methodology for determining naturalized flows. The procedure involves using streamflow gauges that are "unregulated"or "unurbanized", that is, those gauges for watersheds where 10% or less of the drainage area is characterized by reservoir storage or urbanization. A statistical approach would be used to develop naturalized flows for control points in regulated watersheds by relating the characteristics of unregulated watersheds to the characteristics of regulated watersheds. This procedure eliminates the need to evaluate the effects of reservoirs within regulated watersheds. However, either assumptions or an additional data collection is still required to "fill in" missing gauge data, water use data, and return flows.

The three relatively independent statistical procedures for estimating naturalized monthly flow volumes for sites as outlined by the TNRCC (1997) are presented below. The USGS has recommended that Procedure 1 or 2 (or both) be used to provide estimates of naturalized monthly flows for specific sites. Procedure 1 estimates a data set of naturalized long-term monthly flow volumes for any site. Procedure 2 provides estimates of the distribution of naturalized monthly flow volumes. Streamflow measurements for a site, as described in Procedure 3, could provide a third value for naturalized monthly flow volumes, and could be used to verify the values produced from Procedures 1, 2, or both.

Procedure 1

Naturalized monthly flow for long-term (those in unregulated watersheds with at least 40 years record) and short-term stations (those in unregulated watersheds with between 5 and 40 years record) is determined by adding monthly diversions and subtracting return volumes from the corresponding streamflow gauge data. A matrix presenting the statistical ratio of the naturalized monthly streamflow volumes for the common period of record is determined between each long-term station and each short-term station. Specific basin characteristics such as contributing drainage area, major channel length, major channel slope (from the headwaters to the gauge location), and a basin shape factor (the ratio of the major channel length to the mean basin width) are aggregated for each long-term and short-term station. The long-term station with the most pertinent data to each short-term station is identified based on the statistical ratio, relative locations, and basin characteristics. A long-term database of flows for each short-term station is calculated based on the statistical ratio and the database for the long-term stations. The basin characteristics and flow database for each gauging station in the basin are stored in the computer to be retrieved whenever naturalized monthly flow volume for a specific site is desired. This is done using a GIS program, which produces an equation to estimate the long-term monthly flows for the site of concern based on the basin characteristics of the site relative to the basin characteristics and long-term monthly flows of the pertinent station. In cases where two or more stations are deemed to have basin characteristics similarly relevant to those of the site, an equation would be developed for each station and site flows estimated from each station. The finalized site flows will be based on the average of the two estimated flows.

Procedure 2

The USGS suggests that a regionalized database of monthly flow distributions, rather than a database of actual flow volumes, would provide more reliable flow estimates. The flow distributions based on gauged flows and basin characteristics would probably provide better estimates of drought flows for sites than would be provided by Procedure

1. Procedure 2 begins with determining naturalized monthly flow for all stations with at least five years of data by adding monthly diversions and subtracting return volumes from the corresponding streamflow gauge data. Stations are aggregated by hydrologic region, whose equation for estimating naturalized mean monthly flow based on basin characteristic is determined through multi-regression analysis of the naturalized streamflow of each station. The dependent variables in the equations will represent the mean-monthly naturalized flows for each station (e.g., mean flow for January, February, etc.), while the independent variables will represent the basin characteristics for each station. The monthly flow distribution for each station in each region is determined based on their monthly flow volumes. The distribution type that best fits the distribution for specific months and specific basin sizes for the stations is determined. To estimate the mean-monthly flow volumes (e.g., mean flow for January, February, etc.) for a site, GIS-determined basin characteristics of the site along with the basin characteristic-based equation are used. The monthly flow distribution is estimated based on the characteristics for the site and the distribution type previously determined. The mean-computed monthly flows and monthly flow distributions could be used to estimate the monthly flow for any recurrence period. This procedure produces the ability to estimate naturalized monthly flow volumes for specific recurrence periods at any site.

Procedure 3

To estimate naturalized monthly flows for a site, the streamflow discharge at this site is measured, then mathematically adjusted for upstream withdrawals and releases to represent that measurement as naturalized flow. The same time streamflow discharge for a nearby (or several nearby) existing streamflow-gauging station is also naturalized. A ratio of naturalized monthly flow for a site and a nearby gauging station is applied to the naturalized monthly flows for the station in order to estimate naturalized flows for the site.

If several stations are used in the site evaluation, the site's naturalized monthly flows are estimated from each station, and then the average is taken to produce one value. To improve the reliability of this procedure, it is recommended that more than one discharge measurement during different flow conditions be made at each site. If more than one discharge measurement is made for a site, the above process is calculated for each site measurement, and the average of the resulting flow values is taken. This procedure is used in conjunction with Procedure 1 or Procedure 2 above, in order to produce independent values for naturalized flows at sites remote from gauging stations.

The result of the evaluation of the methodologies mentioned to calculate naturalized streamflow is shown in Table 2-1.

Table 2-1. Evaluation of naturalized streamflow methodologies[1]

Criteria	Methodology		
	Traditional	Rainfall-Runoff	USGS
Complexity	Complex	Somewhat complex	Complex
Resource requirements	High	Moderate	Moderate
Scope and availability of data	Extensive data required and much may be missing	Relatively moderate amounts of data required	Relatively moderate amounts of data required
Standardized	Very	New	New
Accuracy	Unknown	Unknown	Unknown
Precision	Unknown	Unknown	Unknown
Theoretical correctness	Acceptable	Moderately acceptable	Moderately acceptable
Acceptability to stakeholders	Very acceptable	Only slightly acceptable	Only slightly acceptable

[1] Source: TNRCC (1997)

2.8.2 Distributing Naturalized Flows from Gauged to Ungauged Locations

Sequences of naturalized flows covering several decades of hydrologic record could be determined at the location of stream gauging stations if upstream abstractions are known or can be approximated. From the perspective of water availability modeling, corresponding sequences of flow at all ungauged sites of actual or proposed water rights must be estimated. Hence, there is a need to develop flow, or specifically, distribute flows at gauging stations to pertinent ungauged locations of actual and proposed diversion or discharge rights.

Collective experience in watershed modeling indicates that watershed characteristics affecting runoff volumes such as antecedent moisture conditions, land cover, and soils are very relevant to the problem of estimating monthly flow sequences for ungauged locations. Topographic characteristics primarily affecting runoff response time such as watershed shape, stream tributary configuration, and watershed and channel slopes, are much less relevant (Wurbs and Sisson, 1999).

2.8.2.1 Methods for Distributing Flows from Gauged to Ungauged Sites

The methods for distributing flows from gauged to ungauged sites range from very simple to the complex and laborious. Wurbs and Sisson (1999) reviewed the general approaches for estimating naturalized flows at ungauged sites. The general approaches include: a) distribution of flows in proportion to drainage area; b) flow distribution equation with ratios for various watershed parameters; c) adaptation of the NRCS curve number method; d) use of stream gauge records to develop regression equations relating flows to watershed characteristics; e) use of recorded data at gauging stations to develop precipitation-runoff relationships; and f) watershed (precipitation-runoff) computer models. Based on these approaches, four alternative methods were presented and evaluated. They recommended the use of either drainage area ratio or NRCS curve number adaptation method for most routine applications in water availability modeling. The general and alternative approaches are summarized below.

a. Distribution of Flows in Proportion to Drainage Area

Application of drainage area ratios is the simplest and most widely-used method for distributing flows from gauged to ungauged sites. In this method, the streamflow per unit area of watershed is assumed constant, and the naturalized flow at the ungauged site is calculated as the naturalized flow at the gauged site multiplied by the ratio of ungauged to gauged areas, mathematically expressed as:

$$Q_{ungauged} = Q_{gauged}\left(\frac{A_{ungauged}}{A_{gauged}}\right) \qquad (2\text{-}5)$$

Alternately, flows could be estimated as a non-linear function of drainage area ratio as

$$Q_{ungauged} = Q_{gauged}\left(\frac{A_{ungauged}}{A_{gauged}}\right)^{N} \tag{2-6}$$

with exponent N being determined from empirical analyses of gauged flows at many different gauging stations.

b. Flow Distribution Equation with Watershed Parameter Rations

As cited by Wurbs and Sisson (1999), Murthy and co-authors (1975) described the early water availability modeling concepts developed by Texas Water Rights Commission and presented equation 2-7 for distributing storm runoff to the subwatersheds between gauging stations:

$$SWRF_i = SRF_j\left(\frac{a_i}{A_j}\right)^{c1}\left(\frac{dd_i}{DD_j}\right)^{c2}\left(\frac{cn_i}{CN_j}\right)^{c3}\left(\frac{rdc_i}{RDC_j}\right)^{c4} \tag{2-7}$$

where:

$SWRF_i$ and SRF_j	=	runoff from watershed i and j, respectively
a_i and A_j	=	the drainage areas of subwatershed i and watershed j
dd_i and DD_j	=	drainage densities defined as the total length of main stream and tributaries per unit drainage area
cn_i and CN_j	=	hydrologic characteristic numbers determined based on soil characteristics and land use in the watershed
rdc_i and RDC_j	=	rainfall distribution coefficients for ungauged subwatershed i and gauged watershed j, computed from monthly rainfall records and their probability distributions

As cited by Wurbs and Sisson (1999), there was no explanation on how the exponents $c1$, $c2$, $c3$, and $c4$ are determined. They presumed that estimates could be developed based on analyses of flows at multiple gauging stations. If $c2$, $c3$, and $c4$ are zero, equation 2-7 reduces to equation 2-6. With the drainage density and rainfall distribution coefficient ratios set equal to one, equation 2-7 reduces to equation 2-8.

$$SWRF_i = SRF_j \left(\frac{a_i}{A_j} \right)^{c1} \left(\frac{cn_i}{CN_j} \right)^{c3} \tag{2-8}$$

Comparison of the above equation with the NRCS curve number method showed that the former provides a linear relationship between the flows at the gauged and ungauged sites while the latter provides a non-linear relationship between flows at different sites.

c. NRCS Curve Number Method Adaptation

The Natural Resource Conservation Service (NRCS) curve number (CN) method is based on the following relationship between rainfall depth (*P* in inches) and runoff depth (*Q* in inches).

$$Q = \left(\frac{P - 0.2S}{P + 0.8S} \right)^2 \qquad \text{where} \quad S = \left(\frac{1{,}000}{CN} \right) - 10 \tag{2-9}$$

$$Q = 0 \ \text{ if } \ P < 0.2\text{S}$$

To obtain volumes, *P* and *Q* (in inches) must be multiplied by the watershed area. The potential maximum retention, *S* in inches, represents an upper limit on the amount of water that can be abstracted by the watershed through surface storage, infiltration, and other hydrologic abstractions. For convenience, *S* is expressed in terms of a curve number *CN*, a dimensionless watershed parameter ranging from 0 to 100. A *CN* of 100 represents a limiting condition of a perfectly impervious watershed with zero retention and thus all the rainfall becoming runoff. A *CN* of zero conceptually represents the other extreme with the watershed abstracting all rainfall with no runoff regardless of the rainfall amount. The NRCS has developed tables of *CN* values as a function of the watershed soil type, land cover/use/condition, and an antecedent moisture condition. For a watershed with subareas of different soil types and land cover, a composite *CN* is determined by weighting the *CN's* for the different subareas in proportion to land area associated with each.

$$Composite\ CN = CN_1(\%\ area\ 1) + CN_2\ (\%\ area\ 2) + \ldots + CN_N(\%\ area\ N) \quad (2\text{-}10)$$

The procedure for distributing monthly naturalized flows at one or more gauging stations to an ungauged site as outlined below is an adaptation of the CN relationship. The required data consists of monthly naturalized flows at the gauging station and drainage areas A and watershed curve numbers CN for both the gauge location and the ungauged site. Optionally, the long-term mean precipitation M may be input for both the watershed and subwatershed for the precipitation adjustment outlined in step 3. The following computations are performed for each month.

Step 1: The flow at the gauge, in acre-feet per month, is divided by the drainage area A_{gauged} and multiplied by a unit conversion factor to convert to an equivalent depth Q_{gauged} in inches.

Step 2: Q_{gauged} is input to the curve number equation (2-9) to obtain P_{gauged} in inches. An iterative method is required to solve equation 2-9 for P. This approximation for precipitation depth is assumed to be applicable to the ungauged subwatershed as well as the gauged watershed. Base flow is being distributed along with storm runoff, all in the same proportion.

Step 3: If the long-term mean precipitation varies between the watershed and subwatershed, the precipitation depth may optionally be adjusted by multiplying P_{gauged} by the ratio of the long-term mean precipitation depth of the subwatershed to that of the watershed to obtain a $P_{ungauged}$ adjusted in proportion to mean precipitation.

$$adjusted\ P_{ungauged} = P_{gauged}\left(\frac{M_{ungauged}}{M_{gauged}}\right) \quad (2\text{-}11)$$

where $M_{ungauged}$ and M_{gauged} are the mean precipitation for the ungauged subwatershed and gauged watershed. Otherwise, $P_{ungauged}$ is assumed equal to P_{gauged}.

Step 4: $P_{ungauged}$ is input into equation 2-4 to obtain $Q_{ungauged}$ in inches, which is then multiplied by $A_{ungauged}$ and a unit conversion factor to flow in acre-feet per month.

d. Regression of Flows at Gauges with Watershed Parameters

As cited by Wurbs and Sisson (1999), the TNRCC (1997) presented a set of three alternative methodologies proposed by USGS for developing naturalized monthly flows at ungauged sites. The first alternative USGS procedure outlined by the TNRCC would be based on a regression study to develop a set of equations to relate flows at ungauged locations to those at selected gauges based on watershed characteristics. The second alternative procedure would be based on relating flow duration-curves at ungauged sites to the flow-duration curves at selected gauges based on watershed characteristics. The third procedure is based on incorporating short-term flow measurements at the otherwise ungauged sites into the analyses. These three procedures are discussed in detail in section 2.8.1.3.

e. Rainfall-Runoff Relationships

There has been a practice of developing relations between precipitation and runoff using recorded data from precipitation and streamflow gauges for a monthly, seasonal, or annual time intervals. Annual data usually exhibit less scatter than monthly data. Runoff volume expressed as an equivalent depth covering the watershed area represents the measured flow volumes for the selected time interval at a streamflow gauge. Precipitation is typically determined by spatially averaging the records of several precipitation gauges in the watershed above the streamflow gauge. Gauged precipitation depths, in inches or millimeters, are related to runoff volume as a depth equivalent in inches or millimeters. Standard regression techniques may be used to express the relationship as an equation. The precipitation-runoff relationship for gauged watersheds is assumed to be applicable to other ungauged watersheds. Precipitation estimates for a subwatershed with no stream gauge are combined with the precipitation-runoff relationship to obtain the runoff depth, which is then combined with the subwatershed drainage area to obtain the volume in acre-feet or other units for the ungauged site.

The general procedure for determining runoff from ungauged subwatersheds of a larger gauged watershed based on spatial variations in precipitation is as follows:

- A curve of annual rainfall depth, in millimeter, versus runoff volume as a depth equivalent, in millimeter, is developed using recorded streamflow and rainfall measurements for numerous watersheds throughout the state.
- Recorded precipitation at appropriate gauges is spatially averaged to estimate the precipitation for a subwatershed. This precipitation depth is combined with the precipitation-runoff relationship to estimate runoff for ungauged areas.
- Flow accumulation computations proceed from upstream to downstream. The runoff volume as an equivalent depth in millimeter from each additional incremental drainage area is determined as noted above. The cumulative volume in m^3 is determined by converting the runoff depths of upstream subareas to m^3 and summing.
- At the stream gauging station at the outlet of the overall watershed, the runoff volume estimated using the generalized annual precipitation-runoff curve is compared to the runoff measured at the gauge. The difference between gauged and estimated is treated as a correction to be distributed back throughout the subareas of the watershed.

The use of precipitation-runoff relationships to distribute flows from gauged to ungauged locations allows the flows to vary between locations in response to spatial variations in precipitation as estimated by recorded measurements at multiple precipitation gauges. However, this procedure by itself does not reflect differences in subwatershed characteristics other than drainage area and precipitation.

f. Computer Models of Watershed Hydrology

Watershed models simulate the hydrologic processes by which precipitation is converted to streamflow. The watershed is the system being modeled, precipitation is the input, and hydrologic processes and runoff are the computed output. Computer models of watershed hydrology incorporate an array of water balance accounting routines or techniques to simulate various hydrologic processes such as surface storage, surface runoff, infiltration, soil moisture, evapotranspiration, groundwater storage/flow, and streamflow. A river basin is divided into sub-basins and flows computed at all pertinent locations. Watershed models can be categorized as single-event or continuous. Single-event models are designed to simulate individual storm events and have no capabilities for soil infiltration capacity and other watershed abstraction capacities to be replenished during extended dry periods. Continuous models simulate long periods of time, which include multiple precipitation events separated by significant dry periods. Most single-event watershed models are designed for quantity-only applications and contain no features for modeling water quality. Most continuous models provide capabilities for analyzing water quality as well as quantity.

Computer models simulating river basin hydrology contribute to a greater understanding of the hydrologic processes governing streamflows in the basin, and provide capabilities for dealing with complexities such as subsurface and surface water interactions. Their major disadvantage is that they require considerable expertise, time, effort, and more input data to be used effectively. Moreover, additional sophistication reflected in a watershed model may not necessarily result in significant improvements in the accuracy of naturalized flow estimates (Wurbs and Sisson, 1999).

2.8.2.2 Comparative Evaluation of Alternative Approaches for Distributing Flows

In their comparative evaluation of methodologies for transposing sequences of monthly naturalized streamflow from gauged to ungauged subwatersheds, Wurbs and Sisson (1999) focused on the following alternative approaches:

a. Distribution of flows to drainage area
b. Distribution of flows in proportion to drainage area, CN, and mean precipitation
c. Adaptation of the NRCS CN method (equations 2-9 and 2-11)
d. Application of the SWAT hydrologic simulation model

They investigated the effect of drainage area, mean precipitation, soil type and land cover, and antecedent moisture condition in distributing naturalized streamflows from gauged to ungauged watersheds using the above-mentioned approaches.

The first two approaches involve multiplying flows by ratios of watershed parameters such as drainage area, mean precipitation, and curve numbers. To transpose naturalized monthly streamflows from gauged to ungauged sites, both follow the relation

$$Q_{ungauged} = C\, Q_{gauged} \tag{2-12}$$

but differ in estimating for the coefficient C. The former uses the drainage area ratios (equations 2-13 and 2-14) while the latter expresses C as a function of mean precipitation M, curve number CN, and other parameters, as well as drainage area A (equations 2-15 and 2-16).

$$C = \left(\frac{A_{ungauged}}{A_{gauged}} \right)^{N} \tag{2-13}$$

$$C = \left(\frac{A_{ungauged}}{A_{gauged}} \right) \tag{2-14}$$

$$C = \left(\frac{A_{ungauged}}{A_{gauged}} \right)^{N1} \left(\frac{M_{ungauged}}{M_{gauged}} \right)^{N2} \left(\frac{CN_{ungauged}}{CN_{gauged}} \right)^{N3} \left(\frac{other_{ungauged}}{other_{gauged}} \right)^{N4} \tag{2-15}$$

$$C = \left(\frac{A_{ungauged}}{A_{gauged}} \right) \left(\frac{M_{ungauged}}{M_{gauged}} \right) \left(\frac{CN_{ungauged}}{CN_{gauged}} \right) \left(\frac{other_{ungauged}}{other_{gauged}} \right) \tag{2-16}$$

Results of their investigation showed that concurrent subwatershed versus watershed flows in individual months are not closely correlated. Long-term means are significantly more closely correlated than flows in specific months. The correlation is dependent on the proportion of the watershed area that is contained within the subwatershed. Flows are best correlated in situations where the ungauged subwatershed covers most of the gauged watershed.

With all of the flow distribution methods, predicted flows vary greatly from the known flows in individual months. All of the methods predicted long-term means and flow-frequency relationships much more accurately than flows in individual months. However, none of the flow distribution methods used reproduced the flow characteristics with a high degree of accuracy. Means are estimated more accurately than flow-frequency relationships and low flows.

The drainage area was found to be the most important watershed parameter. In general, the application of a simple drainage area ratio predicts long-term means and frequency-flow relationships tolerably well. The alternative flow distribution methods performed at about the same level of accuracy. In general, the incremental improvements in accuracy resulting from incorporation of the curve number, mean precipitation, and other data or parameters affecting evapotranspiration and subsurface flow and storage, were relatively small. It was deemed that improvements over the drainage area ratio method are dependent on the relative magnitude of the differences in land cover, soil type, and mean precipitation.

They recommended the drainage area ratio and NRCS CN methods for distributing flows from gauged to ungauged subwatersheds. The decision on which method to use is based largely on judgement. The modified NRCS CN method allows differences in land cover, soil types, and mean precipitation to be reflected in the flow distribution. If these parameters are about the same within some reasonable range of estimation accuracy, the NRCS CN method reduces to the drainage area ratio method. In such case, therefore, the drainage area ratio method is adequate.

2.8.2.3 Uncertainties in Naturalized Flow Determination

The task of developing sequences of naturalized flows for an ungauged watershed necessarily involves uncertainties and inaccuracies. Major areas of uncertainty affecting the accuracy of flow estimates include the following (Wurbs and Sisson, 1999):

a. Precipitation, streamflow, and other hydrologic variables are highly stochastic and vary greatly both temporally and spatially.
b. Rainfall intensities vary drastically over short distances. An intense storm may be concentrated over a particular subwatershed while neighboring subwatersheds receive little or no rainfall. Rain gauges are much too sparsely located to capture the spatial variability of rainfall events with a high degree of accuracy.
c. Watersheds may be highly non-homogeneous with soil, vegetation, land use topography, and other characteristics changing significantly over short distances.
d. Watershed characteristics are difficult to accurately measure.

e. Changes over time in land use and other watershed characteristics are typically not reflected in the process of naturalized gauged flows.
f. The hydrologic processes that transform rainfall to streamflow, such as infiltration, surface storage/flow, subsurface storage/flow, and evapotranspiration are complex. Watershed modeling requires major simplifications and approximations.
g. Streamflow includes both baseflow and surface runoff. Accurately accounting for the separate base flow component, from subsurface sources, and the surface runoff from recent rainfall, is difficult.
h. Channel losses and other interactions between subsurface flows and streamflows are complex.
i. Inaccuracies and uncertainties are inherent in all recorded data including gauged streamflows, gauged rainfall, and data used to naturalize gauged streamflows such as reservoir storage, evaporation rates, and water use.

2.9 Model Performance/Accuracy

A hydrologic model must be reliable and robust as these qualities influence all applications based on the model's output (Perrin, 2001). The conclusions of model assessment generally depend on the objectives, methodology, type of model, test catchments, optimization procedure and the criteria used to assess the performance. The evaluation of the model must take into account its primary objective. In rainfall-runoff modeling, model performance is evaluated in terms of streamflow simulation quality. As cited by Perrin and co-authors (2001), Klemes (1986) proposed a hierarchical assessment methodology to test model performances in calibration-simulation mode (split sample test) or in transposition mode (proxy-basin test). Split sample and proxy-basin tests can include non-stationary conditions in the catchment, in which case, they are called differential tests. This scheme gives a key importance to model verification by assessing the transposability of models in time, space, or under changing environmental conditions. This whole verification approach is powerful and desirable but quite cumbersome and, consequently, seldom fully applied.

In the complex operation of evaluating model performances, assessment criteria must be selected. Numerical criteria are preferred over graphical (qualitative) criteria since the latter are quite subjective as noted by Houghton-Carr (1999). As cited by Perrin and co-workers (2001), Weglarczyk (1998) noticed that there is no best statistical quality criterion for hydrologic simulation models. Hence, if a single criterion is chosen, model verification becomes a partial undertaking.

Following the recommendation of WMO (1986) and ASCE (1993), Perrin and co-workers (2001) used four numerical criteria to assess a model's performance. The assessment criteria are built on three analytical formulations of model error, namely, quadratic, absolute, and cumulative errors. These analytical formulations of model error are expressed in equations 2-17, 2-18, 2-19, and 2-20, respectively.

$$SE = \frac{1}{n}\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{cal,i}\right)^2 \tag{2-17}$$

$$AE = \frac{1}{n}\sum_{i=1}^{n}\left|Q_{obs,i} - Q_{cal,i}\right| \tag{2-18}$$

$$CE = \frac{i}{n}\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{cal,i}\right) \tag{2-19}$$

or in terms of relative (balance error),

$$CE^{*} = 100\left(\frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{cal,i}\right)}{\sum_{i=1}^{n}Q_{obs,i}}\right) \tag{2-20}$$

where $Q_{obs,i}$ and $Q_{cal,i}$ are the observed and calculated streamflows at time step i, Q_{obs} is the mean observed streamflow over the calibration period, and n the number of time steps.

The set of assessment criteria includes the following:

$$CR1\,(\%) = 100\left(1 - \frac{\sum_{i=1}^{n}\left(Q_{obs,i} - Q_{cal,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs}}\right)^2}\right) \tag{2-21}$$

$$CR2\,(\%) = 100\left(1 - \frac{\sum_{i=1}^{n}\left(\sqrt{Q_{obs,i}} - \sqrt{Q_{cal,i}}\right)^2}{\sum_{i=1}^{n}\left(\sqrt{Q_{obs,i}} - \overline{\sqrt{Q_{obs}}}\right)^2}\right) \tag{2-22}$$

CR1 is of the least-square type based on the formulation proposed by Nash and Sutclife (1970). Both assessment criteria, *CR1* and *CR2*, are based on mean square model error *SE*. They vary between 0 and 100% for perfect agreement. They quantify the ability of the model to explain streamflow variance, that is, the improvement achieved by any model in simulating streamflow compared to a basic reference model simulating a constant streamflow equal to the mean observed one. Because of non-constant variance of model errors, *CR1* tends to emphasize large errors, that is, those generally occurring during flood events. *CR2* is a more all-purpose criterion obtained by using root-square transformed streamflow.

The third criterion, *CR3*, is built on the mean absolute model error *AE*. This criterion is potentially useful in a forecasting context wherein the simulations must be as close as possible to the observed values at every time step (Ye et. al., 1997).

$$CR3\,(\%) = 100\left(1 - \frac{\sum_{i=1}^{n}\left|Q_{obs,i} - Q_{cal,i}\right|}{\sum_{i=1}^{n}\left|Q_{obs,i} - \overline{Q_{obs}}\right|}\right) \tag{2-23}$$

The fourth criterion, *CR4*, is based on the mean cumulative error *CE*. It measures the ability of the model to correctly reproduce streamflow volumes over the studied period. It is different from *CR1*, *CR2*, and *CR3* in that it does not measure a departure from observed values at each time step of the simulation, a reason why it cannot be used alone as the calibration criterion.

$$CR4\% = 100\left[1-\left|\sqrt{\frac{\sum_{i=1}^{n} Q_{cal,i}}{\sum_{i=1}^{n} Q_{obs,i}}} - \sqrt{\frac{\sum_{i=1}^{n} Q_{obs,i}}{\sum_{i=1}^{n} Q_{cal,i}}}\right|\right] \tag{2-24}$$

2.10 Performance/Accuracy of Water Availability Models

In general, water availability models that incorporate a priority or rostering of water use are not assessed in terms of performance or reliability. The probable reason is that they are not required to match the historical data, since actual diversions do not match the paper rights (TNRCC, 1998). In its evaluation of the existing water availability models, the TNRCC considered the capability of the models to provide output, which validates the model's ability to replicate the basin.

2.11 Water Allocation Mechanisms

Dinar and co-authors (1997) identified and discussed the concepts, advantages, and disadvantages of the major forms of water allocation such as marginal cost pricing, public or administrative, water markets, and user-based allocation along with country experiences. The major forms of water allocation are summarized below.

2.11.1 Marginal Cost Pricing

A marginal cost pricing (MCP) mechanism targets a price for water to equal the marginal cost of supplying the last unit of that water. Economically efficient or socially optimal allocation of water resources equates water's unit price (the marginal value of water) with the marginal cost. The efficiency criterion maximizes the total value of production across all affected sectors of the economy (Dinar et. al., 1997). In other words, welfare for society as a whole is maximized when water is priced at its marginal cost and is used until the marginal cost is equal to the marginal benefit (Briscoe, 1996, as cited by Perry et. al., 1997).

MCP avoids the tendency to under-price and consequently overuse water. An MCP system could avert overuse because prices would rise to reflect the relative scarcity of water supplied. MCP approaches to water allocation can also be combined with pollution charges or taxes so that the externalities in use of water are embedded in the incentives facing the water user. One of the principal limitations of MCP relates to the difficulties in defining the marginal cost itself, partly because of insufficient information to correctly estimate and monitor benefits and costs. As cited by Dinar and co-authors (1997), Spulber and Sabbaghi (1994) note the following definition problems of marginal cost:

- Marginal cost is multi-dimensional in nature; it includes several inputs such as water quantity and quality.
- Marginal cost varies with the period over which it is measured; it can be a short-run or long-run marginal cost.
- Marginal cost varies depending upon whether a demand increment is permanent or temporary. It is significantly affected by the composition of fixed and variable cost as determined by short and long-term demand.

MCP is also disadvantageous because it tends to neglect equity issues. During periods of shortage or scarcity, if prices increase to the necessary level, lower income groups may be negatively affected. Equity considerations need to be addressed when marginal cost push water prices beyond what lower income groups can afford, and if those who invested earlier have to pay more when a new user is added. MCP is also difficult to implement because it requires volumetric monitoring which is very costly and difficult to administer (Dinar et. al., 1997).

2.11.2 Public Water Allocation

In public allocation, the state or government decides what water resources can be used by the water system as a whole, how to distribute water within different parts of the system, and how to allocate it using guidelines or laws establishing priorities; and often specify the uses to which it can be put (Holden and Thobani, 1996).

Dinar and co-authors (1997) remarked that the main points supporting the argument for public or government intervention in the development and allocation of water resources are as follows: 1) water is traditionally and broadly perceived as a public good, thus, it is difficult to treat water like most market goods; 2) large-scale water development is generally too expensive for the private sector; and 3) the state's role is particularly strong in inter-sectoral allocation as it is often the only institution that includes all users of water resources and has jurisdiction over all sectors of water use.

The track record of the administered systems of water allocation has not been impressive. The administrative methods of water allocation lead to wasteful use of water, poor performance of government-operated water systems, inefficient use of public funds, and failure to address equity and environmental issues (Holden and Thobani, 1996). It is well understood that a queue-based allocation system results in non-marginal pricing of water, which can be a major source of inefficiency (Tientenberg, 1992 as cited by Shah and Zilberman, 1995). A queuing system, which also prohibits water rights trading, offers no incentive for senior water rights holders to adopt water-conserving technologies and practices, which results in less water for the junior rights holder in times of increasing scarcity. The rigidity of the queue-based allocation method is a major reason for the relatively excessive water used by agriculture in the western United States (Shah and Zilberman, 1995).

2.11.3 User-Based Allocation

User-based water allocation is exemplified by farmer-managed irrigation systems. Under this mechanism, allocation rules range from timed rotation, depth of water, area of land, or shares of the flow (Yoder, 1994, as cited by Dinar et. al., 1997). A major advantage of user-based allocation is the potential flexibility to adapt water delivery patterns to meet local needs. Additional advantages include possible improvements in output per unit water, equity, administrative feasibility and sustainability, and political acceptability. For user-based allocation rules to operate requires a very transparent and strong institutional structure, which may not always be available. Local user-based institutions can be limited in their effectiveness for inter-sectoral allocation of water because they do not include all sectors of users. As cited by Dinar and co-authors (1997), Coward (1986) argues that property rights are a critical factor in the viability of organizations for water management.

2.11.4 Water Markets

Market-based allocation of water is referred to as an exchange of water-use rights, compared to a temporary exchange of a given quantity of water between neighboring users, usually called spot water markets (Dinar et. al., 1997). Usually referred to as tradable water rights, it allows the formal transfer of water entitlements among users and is more likely to involve intersectoral transfers than the local, informal water market (Perry et. al., 1997).

Water markets allow water suppliers and consumers to include the opportunity cost of water in their management decisions. Market-based allocation encourages water diversion from low value to highest value uses. The potential benefits of water markets are as follows: 1) water users are empowered by requiring their consent to any reallocation of water and compensation for any water transferred; 2) security of water rights tenure are provided for water users; 3) water users are induced to consider the full opportunity cost of water including its value in alternative uses, thus providing incentives to efficiently use water and to gain additional income through the sale of saved water; 4) water users are provided incentives to take account of the external costs imposed by their water use, reducing the pressure to degrade resources; 5) more acceptability among users compared to volumetric pricing (Rosegrant and Binswanger (1994) as cited by Dinar et. al., 1997). The market-based system is more responsive than centralized allocation of water.

On the other hand, equity issues are often raised within the context of tradable water rights (Holden and Thobani, 1996). Perry and others (1997) argue that water serves many different objectives and properties that make it both a public and a private good. As such, establishing its appropriate price is exceptionally difficult, and even if it becomes possible, the application of price-based instruments is not easy because the flow of water through a basin is complex and provides a wide scope for externalities, market failure, and high transaction costs. The difficulties in the design of a well-functioning water market include measuring water, defining water rights when flows are variable, enforcing withdrawal rules, investing in necessary conveyance systems, sale of water-for-cash by poor farmers, externality and third party effects, and environmental degradation. The pervasiness of externalities such as changes in downstream and return flows, pollution, overdraft of water tables, water logging, and other adverse and often irreversible environmental effects, provides the fundamental argument against water markets (Dinar et. al., 1997). But in a well-defined system where externalities are understood, especially through robust catchment models, these effects can be assessed and accommodated.

2.12 Water rights

The allocation of water is generally based on water rights doctrines rather than on water markets. Laws governing the allocation of surface water vary from region to region. However, these laws have some fundamental similarities and are based on a few general principles. A common element to water allocation laws around the world is that water users are rarely accorded ownership rights to the sources of surface water, such as rivers and large reservoirs. These sources are typically regarded as public property, and individuals are given rights to access such water only for instream uses or withdrawal. Most water disputes probably are based on how these user rights are apportioned and implemented (Shah and Zilberman, 1995).

The extent of water scarcity is an important factor in designing water distribution laws (Shah and Zilberman, 1995). In most countries where water is scarce or costly to access, systems of rights for water use have evolved implicitly through custom or explicitly through bodies of law and regulations. These water rights specify how water in the river is to be divided between alternative uses such as industrial, domestic, and agricultural, as well as between individual water users within a sector. Water rights are generally based on a variant or combination of the three conventional systems, namely; riparian rights, prior rights, and public allocation (Holden and Thobani, 1996).

The riparian rights doctrine states that anyone who possesses land next to a flowing river or stream may take its water as long as enough is left for downstream users. Diversions of water to locations not adjoining the river or stream are prohibited. This right tends to occur in region or areas blessed with plentiful supply of surface water and where strict definition of rights is not crucial (Holden and Thobani, 1996; Shah and Zilberman, 1995).

The prior rights are based on the appropriation doctrine, under which the water right is acquired by actual use over time. Diversions of water are permitted and quotas are allocated among specified parties on a first-come, first-served basis and are subject to the "use it or lose it" rule. The amount of water initially used determines the size of a user's quota (Holden and Thobani, 1996; Shah and Zilberman, 1995). It is allocated by public authorities in other areas.

Warandabi is a water allocation system somewhat similar to the appropriative rights doctrine that is used for supplying canal water to farmers in many parts of India and Pakistan. In this system, farmers take timed turns to withdraw water from a canal or watercourse. Physical location on the watercourse determines an individual farmer's priority level (Shah and Zilberman, 1995). The duration of supply for each farmer is proportional to the size of his landholding to be irrigated within the particular watercourse command (Bandaragoda, 1998).

Water rights are typically defined in one of the following ways: 1) volumetrically as a share of the stream or canal flow or of the water available in a reservoir or lake; 2) in terms of shift or hours of availability at a certain intake; and 3) a combination of both, or conditional upon water availability (Holden and Thobani, 1996). For example, water going into a canal may be based on a share of the river flow, whereas water going to individual farmers may be based on hours of water available at an intake point.

Water rights can also either be consumptive or non-consumptive, temporary or permanent. Permanent consumptive rights are defined in volumetric terms unless there is insufficient water to satisfy all water rights holders, in which case the water is distributed proportionately. Temporary (contingent) consumptive rights, which are particularly useful when there is storage availability, are only honored when all permanent consumptive rights have been met. Non-consumptive rights, usually used for hydropower generation, grant the owner the use of water as long as it is returned to its source at a specified location and quality.

2.13 Transition from Water Rights to Water Markets

The growing demand for water has brought about a radical transformation in water rights as competition for the limited supply intensifies. Market-based allocation of water, which involves transfer or trading of water rights, emerged in response to increasing water scarcity (Sturgess and Wright, 1993). Sturgess and Wright (1993) noted that this was the case for surface water in New South Wales where water markets and enforceable water property rights in the area were largely the outcome of increasing water shortages. As cited by Shah and Zilberman, (1995), Saliba and Bush's (1987) study of the evolution of water institutions and markets in the arid West further supported the view that a combination of growing water demands and reduced emphasis on building new water projects encouraged the move towards water markets in many areas. It is believed that water markets evolve more easily in circumstances where existing allocative mechanisms provide secure and potentially transferable property rights to current holders of water claims. Transition from doctrine-based water rights to water markets has been a subject of many literatures (Sturgess and Wright, 1993; Shah and Zilberman, 1995; Holden and Thobani, 1996; and Perry et.al., 1997, among others).

2.14 Water Markets/Tradable Water Rights Feasibility

Despite the promise that water markets hold, only a few countries have formally established them. The economic argument against tradable water rights rests on the perception of market failure which arises because of the following (Holden and Thobani, 1996):

- There are high transaction costs from setting up a new legal, regulatory, and institutional framework, from defining, measuring, and enforcing water rights, identifying potential beneficial trades, and from making necessary changes in water intakes and conveyance infrastructure to effect the transfers.
- Capital requirements may be high and time horizons long, thus natural monopolies are created which require regulation.
- There are issues of aquifer depletion and return flows.
- There are public good aspects of flood control, pollution control, and disease control along water courses which may justify government intervention.

- There are national security and humanitarian aspects of many water resources which may justify control by the government.
- Using water markets may exclude the poor from access to water.

Results of Shah and Zilberman's (1995) study showed that the transition from water rights to water market could be rendered socially undesirable, or hindered politically by the existence of high transaction costs, unavailability of efficient irrigation technologies, and by output market considerations such as inelastic demand.

Perry and others (1997) defined a necessary and sequential set of preconditions for the beneficial introduction of market forces into the allocation of water as follows:

- The entitlements of all users under all levels of resource availability are defined and include specified assignments to social and environmental uses.
- Infrastructure is in place to deliver the defined entitlements.
- Measurement standards are acceptable to the delivering agency and the users.
- Effective recourse is available to those who do not receive their entitlements.
- Reallocations of water can be measured and delivered, and third-party impacts in quality, quantity, time, and place can be identified.
- Effective recourse is available to third parties affected by changes in use.
- Users must be legally obligated to pay defined user fees through effective legal and policy procedures.
- Large-scale transfers of water with and between sectors must be subject to approval and relevant charges by regulatory agencies.

2.15 Water as an Economic Good

The Dublin Conference (International Conference on Water and the Environment) in 1992 produces a statement which contained four guiding principles for action at local, national, and international levels and set out an agenda for reversing trends of overconsumption, pollution, and rising threats from drought and floods (Rodda, 1995 as cited by Wall, 1997). Principle 4 stated that water has an economic value in all its competing uses and should be recognized as an economic good. It stated that failure in the past to recognize the economic value of water has led to wasteful and environmentally damaging uses of the resource. It said that managing water as an economic good is an important way of achieving efficient and equitable use, which also encourages conservation and protection of water resources. Within this principle, the Dublin Conference asserted that it is vital to recognize first the basic right of all human beings to have access to clean water and sanitation at an affordable price.

There is wide interest in and support for the idea of treating water as an economic good. However, its role as a basic good, a merit good, and a social, economic, financial, and environmental resource makes setting of appropriate price a difficult task. Water has several characteristics that make the role of the public sector in its development and management more essential than for other goods that can be handled efficiently in a market framework (Perry, et. al., 1997; Dinar, et. al., 1997). Economic treatment of water, especially pricing, should be in balance with water as a social good, considering the basic needs of the poor and their limited ability to pay for it (Winpenny, 1995).

2.16 Economic Principles of Scarce Resource Allocation

Water resources that comprise surface water (rivers, lakes, and reservoirs), groundwater, floodwater, and desalinated water are essential inputs for various economic sectors such as municipal, industrial, agricultural, hydropower, recreational, and environmental. With increasing population growth rates, increasing per capita consumption, and dwindling supply both in terms of quantity and quality, access to limited water resources is becoming more competitive. Thus, there is a pressing need to allocate water among sectors more efficiently. It is necessary to make economic decisions compatible with social objectives, that is, efficiency and equity considerations. While economic efficiency is concerned with the amount of wealth that can be generated by a given resource base, equity deals with the distribution of the total wealth among the sectors and individuals of society (Dinar, et. al., 1997).

2.16.1 Equity

Natural resources, especially water, has been traditional viewed as common good and has been allocated on the basis of social criteria. For this reason, equity whose objectives are specifically concerned with fairness of allocation across economically disparate groups has been a basis for water resource allocation. Equitable allocation of a scarce resource means that all sectors or parties have a basic right to the resource services regardless of their ability to pay. As such, equity principles may or may not be consistent with efficiency objectives (Dinar, et. al., 1997).

2.16.2 Economic Efficiency

Allocation of scarce resources to different sectors can be viewed from a purely economic point of view as a portfolio of investment projects, i.e., the economic sectors use the limited resource as capital and produce returns. In economically efficient allocation, the marginal benefit from the use of the resource should be equal across sectors in order to maximize social welfare. In other words, the benefit from using one additional unit of the resource in one sector should be the same as it is in any other sector (Dinar, et. al., 1997).

2.17 Criteria for Allocation

Many water allocation schemes attempt to combine efficiency and equity objectives. Appropriate means of allocation are necessary to achieve optimal allocation of the scarce resource. There are several criteria used to compare forms of water allocation (Howel, et. al., 1986, as cited by Dinar, et. al., 1997):

- Flexibility in the allocation of supplies, so that the resource can be shifted from use to use and place to place as demand changes, making it possible to equate marginal values over many uses with least cost.
- Security of tenure for established users, so that they will take necessary measures to use the resource efficiently.
- Real opportunity cost of providing the resource is paid for by the users, so that other demand or externality effects are internalized. This allows the allocation to account for environmental uses with a non-market value (such as providing habitat for wildlife). This also directs the employment of the resource to activities with the highest alternative values.
- Predictability of the outcome of the allocation process, so that the best allocation can occur and uncertainty, especially for transaction costs, is minimized.

- Equity of the allocation process should be perceived by the prospective users, providing equal opportunity gains to every potential user from utilizing the resource.
- Political and public acceptability, so that the allocation serves values and objectives, and is therefore, accepted by various segments in society.

Other criteria include the following:

- Efficacy, so that the form of allocation changes an existing undesirable situation such as depletion of groundwater and water pollution, and drives towards achieving desired policy goals (Winpenny, 1994).
- Institutional and administrative feasibility and sustainability, to be able to implement the allocation mechanism, and to allow a continuing and growing effect of the policy (Winpenny, 1994).
- Productivity, to direct the employment of the resource to activities whose desired output per unit input is greater, optimizing the use of water. It can either be related to the physical mass of production or to the economic value of produce per unit volume of water (Molden, 1997; Molden and Sakthivadivel, 1999). It is the same as flexibility in the allocation of supplies cited earlier.
- Effective water use efficiency, to provide a meaningful and useful tool to bridge micro- and macro-planning perspectives and to incorporate water quality implications in the strategic search for real water conservation opportunities (Keller and Keller, 1995). This criterion would be an outcome of the security of tenure mentioned earlier.
- Environmental sustainability, to conserve and protect the limited water resources and incorporate the environmental effects into economic, technical, and social criteria used to evaluate alternative resource-related undertakings (Winpenny, 1994; Loucks and Gladwell, 1999). It would be an outcome of the the real opportunity criterion enumerated earlier. Optimal allocation of water resources requires full recognition of the environment as a water user and the ability to identify the minimum water requirements to support and maintain aquatic eco-systems (Geyer-Allely, 1998).
- Integrated resource management, to consider supply and demand-side pressures and aims to minimize waste, maximize use efficiency, and limit consumption to sustainable levels. The high interdependency among water users (due to the movement of water within the hydrologic cycle) requires a holistic approach. An

integrated approach is more likely to address allocation issues and conflicts (Geyer-Allely, 1998).

- Stakeholder participation, to give water users a sense of ownership of the allocation program and therefore, responsibility for it.

2.18 General Conclusion

Based on the literature reviewed, the following conclusions were derived:

- Knowledge of the amount of available water is fundamental to effective and sustainable water resources management. Factors affecting its availability and reliability, such as river basin hydrology and institutional considerations like water rights, should be adequately assessed. With intensifying competition for water, effective allocation procedures that minimize and help resolve conflicts must be developed and implemented. Effective strategies for obtaining more productivity while maintaining or improving the environment must be formulated.

- Water has an economic value in all its competing uses. Managing it as an economic good – both as a public and private good – is an effective approach towards achieving efficient, productive, and equitable use as well as promoting conservation and protection of water resources. A rational water allocation scheme should combine economic efficiency and equity considerations.

- In the face of growing water scarcity and after the basic level of water service is attained, there are reasons to believe that a market-based water allocation might function better than government-administered allocation in terms of improving water use efficiency and productivity, and in rational distribution of water among competing uses. For beneficial application of market tools into the allocation of water, a necessary and sufficient set of preconditions for the operation of an effective water market such as well-defined, quantifiable, and transferable property rights and institutional mechanisms must first be in place. The development of water markets; identifying, establishing, and adjudicating water rights; quantifying, monitoring, and regulating externalities; and providing the appropriate legal and institutional support remain vital responsibilities of the government.

- Assessment of water resources should include a realistic forecast of the demand for water, based on projected population growth, economic growth, and a consideration of different management scenarios, taking into account existing investments and those likely to occur in the private sector. Since streamflow and other hydrologic parameters are characterized by great variability and randomness; and that its state and movement through a basin is highly interdependent and provides for a wide scope for externalities, market failure, and high transaction costs; modeling could be a useful way of throwing light on fundamentals to effective water management, such as water availability and reliability estimates.

- Water availability models could provide considerable flexibility for assessing hydrologic and institutional water availability and reliability, and evaluating alternative reservoir system operating plans and related water management strategies. However, determining natural hydrology and defining actual management practices are prerequisites to representing them in a computer model.

CHAPTER 3
METHODOLOGY

3.1 Introduction

The research study aimed at assessing the utility of WRAP in modeling the hydrologic and institutional water availability and reliability of the Oroua River for the existing water rights as well as simulating alternative water use and management scenarios. This chapter describes and discusses the specific methods and procedures carried out to achieve these objectives. It also provides the rationale for the selection of the simulation model used.

3.2 Rationale for WRAP Selection

Since WRAP is specifically designed to facilitate incorporation of a water rights priority system in water availability modeling, it was deemed capable of providing considerable flexibility for modeling various rules specified in water rights permits governing water allocation and management. The priority scaling option in WRAP-SIM allows rights associated with specified water use types to be conveniently adjusted. It could be helpful in figuring out possible impacts of prioritizing a particular water use over other uses on water availability. For example, all municipal rights could be given priority over all agricultural rights in a particular simulation run. WRAP's provision for specifying instream flow requirements could be used to evaluate the impacts of the minimum flow determined for the Oroua River on existing water rights throughout the river basin.

WRAP has known field applications and citations in technical literature published in refereed journals. Moreover, the model is well-documented and ownership is in the public domain, allowing for possible source code modifications without having to deal with property rights issues.

Furthermore, TNRCC (1998) initiated an independent evaluation of the 24 identified hydrologic models for the State's water availability modeling project. It assessed WRAP as having an advantage in handling matters concerning priority systems, channel losses/gains, and public domain ownership. Its capabilities were assessed to be at par with the evaluated water availability models (Appendix 3-1) in terms of: performance/accuracy; ability to place water rights at their proper geographic location and to individually account for them in the model; ease in incorporating or modifying model time step and stochastic capability; ability to deal with special conditions in the water rights (variable diversion rates, priority dates, and conditional transfers or water rights exchanges); and manner of handling reservoir/system operations, return flows and water reuse, instream flows, bay and estuary inflows, groundwater interactions, water allocation, and water quality.

3.3 General Methodology

The water availability modeling was done in two phases. The first phase involved developing sequences of monthly naturalized streamflows covering the 1993-1998 period-of-analysis at all pertinent locations. The second phase involved simulating the water rights and river system given the input sequences of naturalized flows. This is to determine regulated and unallocated flows and water supply reliability and streamflow frequency indices. The river basin hydrology was represented in WRAP by naturalized streamflows at each pertinent location for each month of the hydrologic period-of-analysis. The Oroua River catchment management and water use requirements were represented in WRAP in terms of water rights.

The general framework of the research methodology is shown in Figure 3-1. Information on the stream flow for the Oroua River, water rights, water allocation and management practice, and relevant maps was sourced from MWRC (see Appendix 3-2). Based on the available data, the period-of-analysis was determined, the study area was delineated, and some flow-related inputs were estimated.

The water availability modeling process started with the development of the spatial configuration of a river/use system in WRAP. The pertinent features of the river basin system such, as streamflows, abstractions, discharges or inflows, and instream flow requirements, were assigned control points to model their spatial and hydrological connectivity. A set of models of the hydrologic characteristics of the Oroua River, current water use, and management practices was built by developing input information for each WRAP program in the format of records and associated input files (see Appendix 3-3 for the various WRAP input files and records). A set of WRAP models of

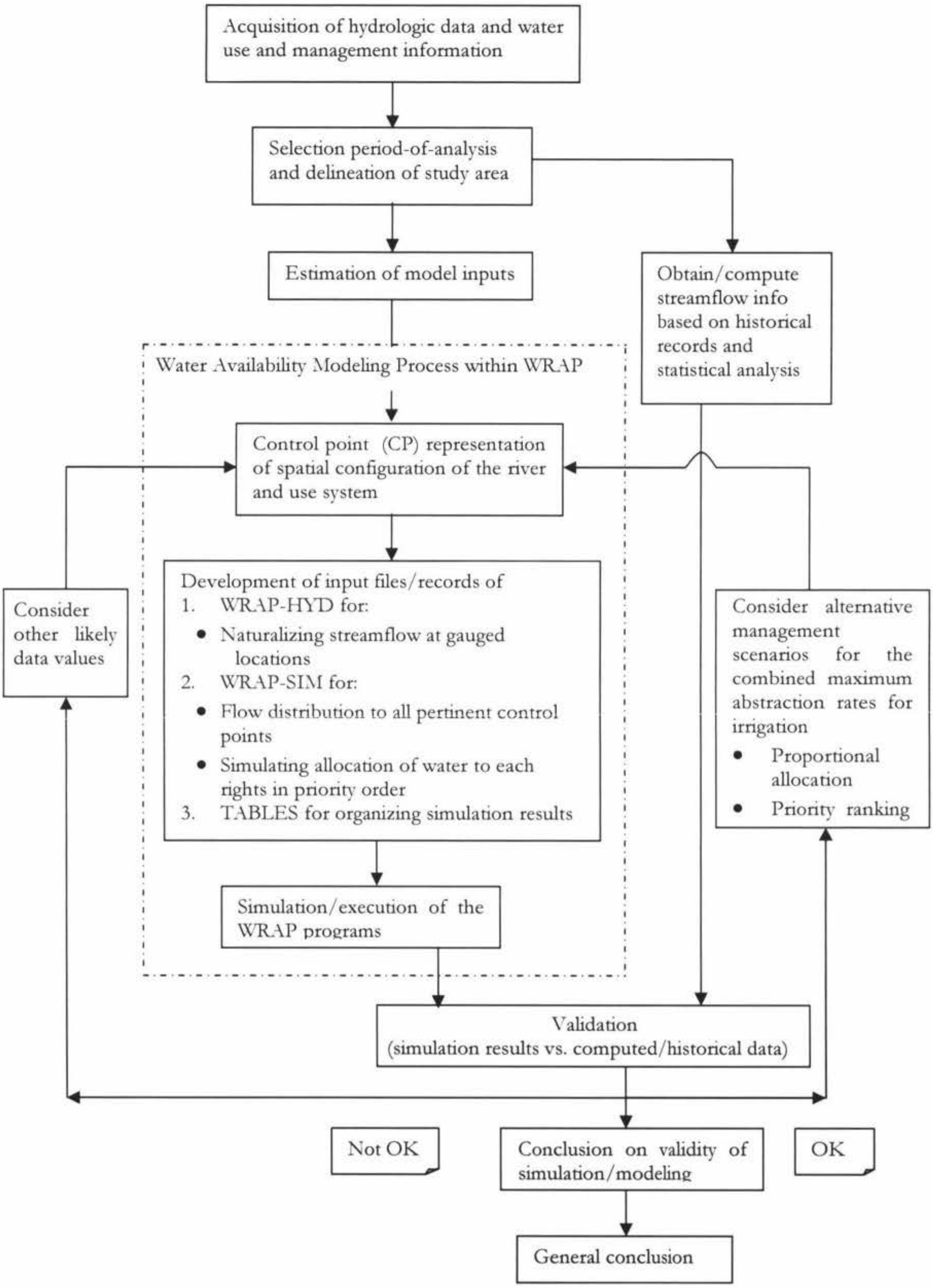


Figure 3-1. General Framework of the Research Methodology

alternative water allocation was also built. The WRAP program was run to estimate the natural flows, regulated and uncommitted flows at each control point, and associated reliability and frequency indices. Sample parallel manual calculations were done to check whether the built WRAP models behaved as intended. Sections 3.5 to 3.12 give the details of the WRAP modeling of the Oroua River water allocation and management.

3.4 Simulation in WRAP

The outline of WRAP simulation is shown in Figure 3-2. The 1993-1998 monthly naturalized streamflows for the Oroua River at Almadale and Kiwitea at Spur Road stations were developed in WRAP-HYD. These naturalized flows were used as input to WRAP-SIM to determine regulated or actual physical flow, and unappropriated or unallocated flows at all control points.

Simulation in WRAP-SIM proceeded in the following order: 1) all input data, except naturalized flows, were read and organized at the beginning of a WRAP-SIM execution; 2) water rights were ranked in priority order and watershed parameters were manipulated for flow distribution; and 3) the simulation was then performed in a set of nested loops. The simulation proceeded by year and within each year, by month. Within each month, it proceeded by water right in priority order.

The annual loop began with reading the streamflow for each month and the distributed flows from gauged to ungauged control points. For each month of the simulation, WRAP-SIM performed water accounting computations for each water right, in turns, on a priority basis. The computations were performed in three stages for each water right. First, the amount of streamflow available to the right was determined. Second, water balance computations were performed to compute streamflow depletion, return flows, diversion and diversion shortages. Lastly, upon the completion of the water right computation, both regulated or actual physical flow and unallocated flow at all control points were computed through a series of adjustments reflecting the effects of the water right. TABLES was used to organize and summarize the simulation results, as well as compute the water supply reliability and streamflow frequency indices.

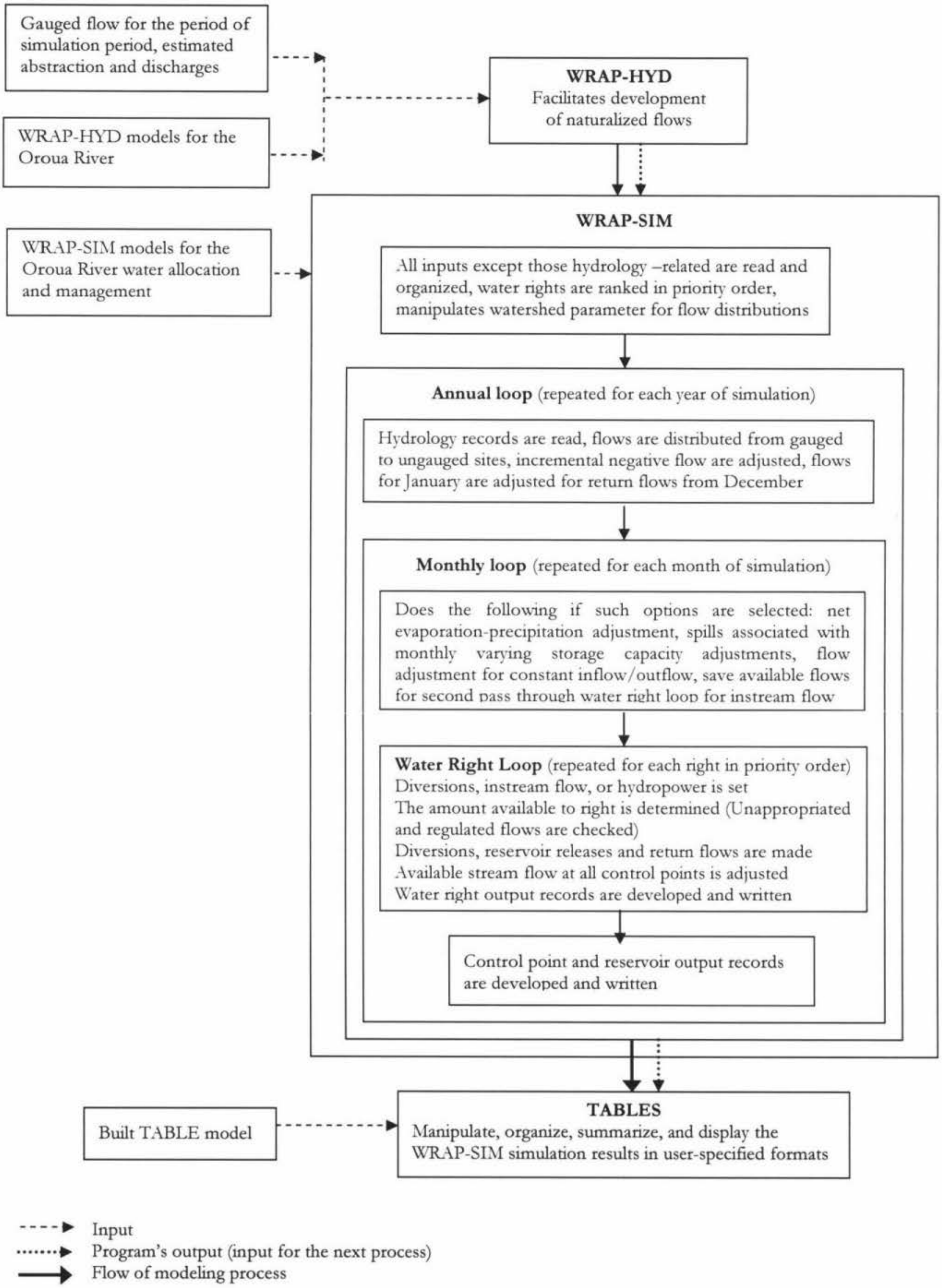


Figure 3-2. Flowchart of WRAP Simulation (Wurbs, 2000)

3.5 Delineation of the Study Area

The study adopted the 1993-1998 hydrologic period-of-analysis and covered the Kiwitea sub-catchment and part of the Oroua catchment upstream of the old Kawa Wool gauging station. The delineation of the study area and selection of the period-of-analysis were mainly based on the availability of flow and water use data. Flow records for Kiwitea Stream at Spur Road gauging station were available from 1977 to 1998, and back to 1948 for the Oroua at the Almadale gauging station (though with a gap from 1979-1992). Other gauging stations within the catchment had a much shorter record. In the case of water rights records, almost all existing rights within the catchment have effective dates from 1990 onwards. However, it is more likely that some of these abstractions or discharges had been occurring in earlier times. Based on records, all existing rights were in effect by 1997.

A 30 to 80-year period-of-analysis would provide a more accurate representation for actual modeling applications (Wurbs, 2000), but available concurrent flow and water uses for the Oroua catchment had a much shorter period-of-record. This study opted to use a recent actual flow data (1993-1998 record) in evaluating the utility of WRAP for the Oroua River as a water availability assessment and management tool to minimize assumptions that have to be made. Estimates and projections of average water demand and supply conditions should be made in terms of the minimum dry season – not in terms of annual averages (Seckler, 1996). During the last ten years, the 1997-1998 period is the driest period that affected most parts of the country (NIWA as cited by Recile, 1999) caused by the El Niño phenomenon.

3.6 Data Analysis and Generation

Except for the old Kawa Wool gauging station that was washed away by a flood in 1992, was no downstream gauging station whose flow record could be used to validate the simulation result by comparing the actual and the simulated regulated flows. An estimate of the regulated flow for the old Kawa Wool gauging station during the selected period-of-analysis was generated using a group-based approach proposed by Elshorbagy and co-authors (2000).

The procedure included the following: 1) segmentation of the monthly streamflow series for Almadale, Kawa Wool, and Spur Road stations into groups; 2) investigation of the group's normality, trend, seasonality, and correlation structure in relation to data groups; and 3) modeling the data group in order to estimate the 1993-1998 monthly regulated flows for the old Kawa Wool station. Group segmentation of the data was based on the graph of monthly distance from the series mean flow as well as on monthly box-plots. Test for seasonality also made use of these two graphs.

Normality within the groups was tested using kurtosis and skewness coefficients, while the correlation structure among groups was analyzed using autocorrelation and partial autocorrelation functions. The seasonal Kendall test for trend and the seasonal Kendall trend slope estimator were used to assess the significance and magnitude of any trend, respectively. The selection of a regression model to predict the likely regulated flow for the old Kawa Wool station for the chosen period-of-analysis was based on the result of the above analyses. A box plot, the Mann-Kendall test for trend, and the autocorrelation and partial autocorrelation functions are shown in Appendix 3-4.

3.7 Control Point Representation of the Spatial Configuration of the Oroua River Basin System

Gauged streamflows, abstraction and discharge rights, and target instream flow requirements were assigned a control point (CP) to denote their spatial connectivity and model the effects of a right on other rights. Most of the rights were each assigned one control point while some were grouped together in one control point. Grouping of water rights in a control point was based on relative location of a right to nearby rights as determined by its associated drainage area. Neighbouring rights with practically the same drainage area were grouped in one control point. Information on water rights is summarized in Table 3-1. The spatial configuration of the Oroua River is shown in Figure 3-3.

Table 3-1. Water Rights Information

Water Right/Instream Flow Identifier	Control Point	Permitted Volume (m3/day)	Total Drainage Area Upstream (ha)*
Abstraction Rights			
MWC912876	CP1	2,592	22,671.8
100790	CP2	9,000	28,878.1
4514	CP3	682	30,440.0
IF Almadale Station	CP3	79,056	30,440.0
3600	CP3	960	30,440.0
3675	CP4	1,320	31,240.2
4586	CP5	7,000	31,263.0
4487	CP6	600	31,798.0
4447	CP6	1,225	31,798.0
MWT820019	CP7	259	31,992.0
6092	CP8	42	2,909.9
MWC912875	CP9	768	14,953.7
MWT701526	CP10	432	16,036.9
6273	CP11	2,600	23,517.8
IF Spur Rd Station	CP12	8,208	23,860.7
4796	CP14	29	24,443.2
6105	CP15	227	56,898.1
MWT690185	CP16	6,819	57,100.06
Discharge Rights			
6096	CP2	216	
5071	CP11	20	
4788	CP14	7	
4337	CP15	36	
4222	CP16	100	
4219	CP16	2,000	
4220	CP16	8,400	
4223	CP16	1,495	
MWC912862	CP17	19	

*MWRC (through personal communication)

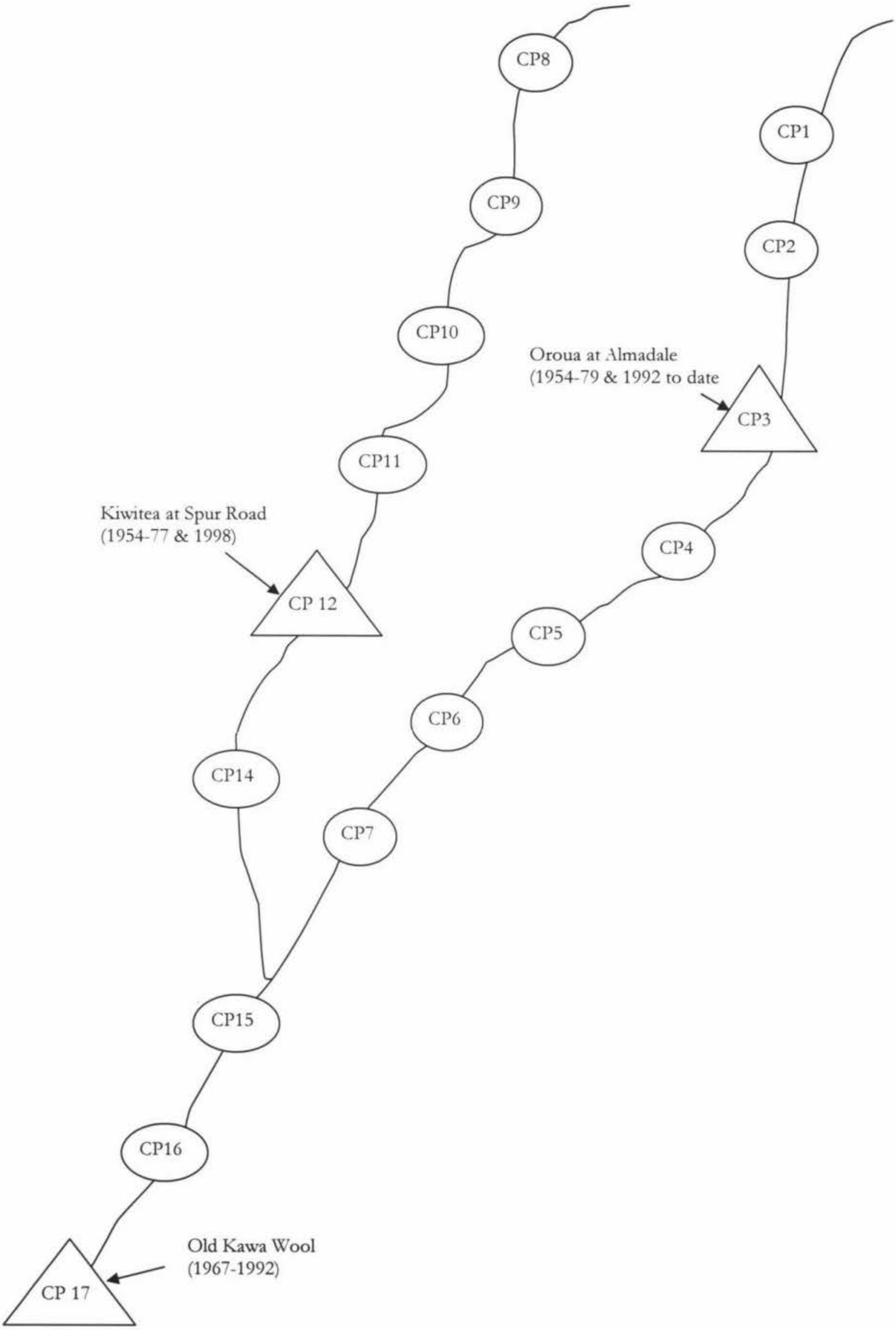


Figure 3-3. Control Point Schematic of the Delineated Oroua River Basin System

3.8 Estimation of the Naturalized Flow

The objective of the flow naturalization process was to develop a series of flows, from which water right demand were subtracted to determine available and unallocated flows. A general guideline followed to estimate naturalized flows was to avoid or minimize the possibility of overestimating the naturalized flows due to addition of a quantity of water that never occurred. Overestimating naturalized flows will overestimate available water (TNRCC, 1997).

To estimate naturalized flows, gauged flows at selected stations were adjusted by adding known or estimated abstractions and subtracting estimated discharges. This traditional method was selected over the rainfall-runoff and statistical approaches due to its standardization and more acceptable theoretical correctness, as assessed by TNRCC (1997).

However, except for water right 100790 held by the MDC for Feilding water supply, records of actual monthly water withdrawals and discharges were not available. Possible water takes and discharges by other rights were estimated based on the assumption that these rights (except those for irrigation purposes) used the same percentage of their permitted volume as water right 100790. Abstractions for the purpose of irrigation were assumed to have occurred only during the relatively drier months of November to March where irrigation is more likely to occur and set equal to zero for the remaining months of the year. Return flows from irrigation were assumed to be practically negligible. Thus, there were no quantities subtracted to reflect them. This assumption was based on the fact that Almadale station is upstream of most irrigation abstractions. The effect of three water abstractions for the purpose of irrigation upstream of the Spur Road station would be minimal. Also, irrigation return flows would be to groundwater so the effect would be low.

Sequences of net streamflow adjustment values representing actual and estimated abstractions, less estimated discharges upstream of the selected gauging stations, are shown in Appendix 3-5. These values were used as input to WRAP-HYD which was used to facilitate computation of naturalized flows for all control points or water rights locations.

The built WRAP-HYD model for the portion of Oroua catchment studied is shown in Appendix 3-6. A parallel manual calculation of naturalized flow at all control points was done to check whether the built model worked as expected.

3.9 WRAP-SIM Model for Simulation of the Oroua Water Management

The simulation of current management methods for surface water abstractions in the Oroua catchment consisted of two scenarios, namely, allocation based on permitted rates and allocation schemes at times of low river flows. The first scenario simulated the "usual" or high river flows allocation management wherein a right may abstract water up to its permitted rates without restrictions. The second scenario dealt with the allocation scheme that restricts abstraction rates based on a monthly flow threshold. It also deals with the allocation rule that suspends irrigation permits while reducing those for public water supply when flow at Almadale and/or Spur Road gauging stations reached the specified minimum levels.

Two sub-scenarios were simulated under the first scenario: full consented abstraction rates of existing rights occurred at all times; and estimated abstraction rates of existing rights. Simulation based on full permitted rates could be used to assess hydrologic and institutional water availability and reliability for the existing water rights in the Oroua River for regulatory and water right permitting purposes. Meanwhile, simulation based on estimated abstraction could be useful for planning purposes. On the other hand, simulation outputs for the low-flow allocation scenario could be used in identifying the likely impact in terms of meeting the specified instream flow requirements, the existing water rights, and the possible water use efficiency of the allocation schemes at times of low river flows.

Pertinent files and records for the above simulation scenarios were supplied with input data. Naturalized flows for CP3 (Almadale station) and CP12 (Spur Road station) were listed in the streamflow (IN) record and distributed to ungauged control points using the drainage area ratio method entered in water right (WR) record. Information on the annual permitted volume, the associated control point, type of water right, computation of instream flow requirement, and water use identifier were supplied in WR and instream flow (IF) records. Changes in permitted targets were effected in either monthly water use coefficient (UC) or WR records. Grouping of water rights based on type of use and monthly distribution factor of permitted rates were modeled using UC record. The latter was computed based on actual usage of WR-100790 and assumed to be true for the rest of the diversion rights. All water abstraction rights were modeled as Type 1 right, allowing their diversion requirement to be met from available streamflow. The specified minimum flow thresholds of 915 lps and 95 lps for Oroua at Almadale and Kiwitea Stream at Spur Road, respectively, were represented as instream flow requirements at these gauging locations. They were also assigned to downstream water rights locations along their respective reaches to maintain and account for them in determining the water available for downstream rights and additional rights. A Type 0 instream flow computation was used for the simulation to determine any shortages in meeting an instream flow requirement. Water discharges were not included in the simulation – equating them to zero. Though this might not be the case, setting them equal to zero when their actual rates are unknown would minimize the possibility of overestimating the available water (TNRCC, 1999). The built WRAP models are shown in Appendices 3-7 to 3-8.

Water allocation in the Oroua River is based on water use type rather than ranked priority system. During times of high river flows, it could be mimicked by an upstream-to-downstream priority allocation, wherein a right is allowed to abstract water up to their permitted rates and water available is only affected by upstream rights. During times of low river flows, a use type-based restriction and/or suspension of water permit takes effect whenever monthly and minimum flow thresholds are observed at Almadale and Spur Road stations. Abstractions for municipal supply are prioritized over industrial and irrigation purposes. The Target Option (TO) record, designed to allow building of abstraction and instream flow targets as a function of naturalized/regulated/unallocated flows and streamflow depletions, was explored to model this allocation. Other related target-building features, such as Target Series (TS), Drought Index (DI/IS/IP) records, and the Monthly Limit (ML) record for specifying system operating rules and their combinations, were investigated.

3.10 Modeling of Alternative Management Scenarios

The two alternative management scenarios focused on apportioning the combined maximum abstraction rates for the purpose of irrigation. The first one involved proportional allocation among restricted irrigation rights (those without a permit as of 21 April 1994) after all unrestricted irrigation rights (those holding a permit at 21 April 1994) had diverted their requirements. The second allocation scenario adopted a ranked priority system based on weighted criteria to apportion the allowed combined maximum abstraction rates among irrigators regardless of the date the permits were held.

3.10.1 Proportional Allocation for "Recent" Irrigation Rights

The total permitted rates of qualified rights, under the maximum abstraction rates rule, only comprised about 37 and 25 percent of the allowed combined maximum abstraction rates for rights taking water from the Oroua River and Kiwitea Stream, respectively. This simulation scenario apportioned the remaining water among irrigation-related rights granted after 21 April 1994 based on the abstraction rates historically granted. The proportional share for each of these rights was determined by the product of its full permitted rate and the ratio of unused rates to sum of their full permitted rates (Table 3-2). It was entered as the new permitted target of the associated right. The developed WRAP model for this management scenario is shown in Appendix 3-9.

Table 3-2. Apportioning of the Combined Maximum Abstraction among "Recent" Irrigation Rights*

	Full Permitted Rates	Allowed individual abstraction under the Maximum Abstractions Rates Rule	Abstraction rates under proportional allocation scheme
1. Oroua River			
WR-4514	7.9	0.0	2.2
WR-3675	15.3	15.3	15.3
WR-4586	81.0	0.0	22.8
WR-4487	6.9	0.0	2.0
WR-4447	14.2	0.0	4.0
WR-MWT820019	3.0	3.0	3.0
WR-6105	2.6	0.0	0.7
Total	130.9	18.3	50.0
Maximum Combined abstraction		50.0	
% of Max. Rates		36.6	100.0
Sum of restricted right rates		*112.7*	
Unused to sum of restricted rates ratio		*0.28*	
2. Kiwitea Stream			
WR-6092	0.5	0.0	0.2
WR-MWT701526	5.0	5.0	5.0
WR-6273	30.1	0.0	14.6
WR-4796	0.3	0.0	0.2
Total	35.9	5.0	20.0
Maximum Combined abstraction		20.0	100.0
% of Max. Rates		25.0	
Sum of restricted right rates		*30.9*	
Unused to sum of restricted rates ratio		*0.48*	

*rates in lps

3.10.2 Rostering Irrigation-Related Abstractions During Low Flows

A provision for rostering abstractions during low flows is included in the OCWA Regional Plan. An alternative scheme involving a ranked priority allocation based on weighted criteria, such as: prior use of water; riparian; irrigation system efficiency; productivity; investment; and equity or social consideration. These were considered in apportioning the specified combined maximum abstractions for all rights under irrigation. Since information on these criteria were not readily available, an arbitrary priority ranking based only on prior use of water indicated by the permit date and upstream-to-downstream location was adopted. An arbitrary weight value of 0.75 and 0.25 for the prior use and the natural priority location, respectively, were used. The computation for determining the priority ranks provided as inputs to the WRAP model for this simulation scenario (Appendix 3-10) is summarized in Table 3-3.

Table 3-3. Priority Ranking of Irrigation Rights

Water Rights	Control Point	Criteria/Weights		Weighted Priority	Priority Rank*
		Prior Use (0.75)	Natural Priority (0.25)		
Along Oroua River					
WR-4514	CP3	3	1	2.5	4
WR-3675	CP4	2	2	2	2
WR-4586	CP5	5	3	4.5	5
WR-4487	CP6	6	4	5.5	7
WR-4447	CP6	7	5	6.5	8
WR-MWT820019	CP7	1	6	2.25	3
WR-6105	CP15	4	7	4.75	6
Along Kiwitea Stream					
WR-6092	CP8	2	1	1.75	3
WR-MWT701526	CP10	1	2	1.25	2
WR-6273	CP11	4	3	3.75	5
WR-4796	CP14	3	4	3.25	4

*Rank 1 is reserved for those unrestricted rights such as municipal abstractions

3.11 TABLES for Organizing and Summarizing the Simulation Results

The subprogram TABLES was run to develop monthly summary tables for the water rights and control points using the associated 2SWR and 2SCP records. It was also used to compute period and volume reliabilities and flow frequency statistics for naturalized, regulated, unallocated streamflow, and instream flow shortages for the control points through 2REL and 2FRE records. Tabulated values for naturalized, regulated, unallocated, and diverted flows and water shortages for the period-of-analysis were generated through their associated records.

3.12 Validation of Simulation Results

Parallel manual calculations for naturalized flow estimation and all simulation scenarios were done to verify whether the WRAP models for the Oroua River behaved as intended. They included the whole period-of-analysis for naturalized flow determination and a sample month for the simulation of water allocation practice. February 1998 was selected for the sample calculation since it was within the driest period in the POR (NIWA) and had the highest actual to permitted abstraction ratios indicating the closest matching of paper right and actual diversion rates.

Results of the simulation were checked against results of manual calculation. The simulated regulated flows for the whole period-of-analysis were compared with the actual gauged flows measured at the Almadale and Spur Road stations.

The validity of the drainage area ratio method as a flow distribution was assessed using linear regression and correlation techniques and flow ratio analysis. For the correlation and regression techniques, the idea was to set the y-intercept equal to zero to obtain a regression model where flow at a station is expressed simply as a constant times the flow on another station. The slope coefficient m determined by the zero-intercept $(b=0)$ linear regression could be related to drainage areas (TNRCC, 1999). Theoretically, a high correlation coefficient for a pair of stations would be associated with relatively small difference in drainage areas.

In flow ratio analysis, the basic concept was to evaluate the capabilities for predicting naturalized flows at subcatchments ($Q_{subcatchment}$) from assumed known flows from a larger catchment ($Q_{catchment}$,) based on the relationship, $Q_{subcatchment} = C\ Q_{catchment}$, or distribution of flows in proportion to ratios of watershed parameters C. The naturalized flow ratios for a pair station were normalized by dividing them by their respective drainage areas. These flow ratios would all be 1.00 if flows were strictly proportional to drainage area (TNRCC, 1999).

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discussion of the water availability modeling process for a portion of the Oroua River catchment using the Water Rights Analysis Package (WRAP). It focuses on the following: 1) the utility of WRAP model in developing naturalized flows and simulating the water allocation management; 2) the simulated water availability and reliability estimates; and 3) the alternative management scenarios simulated using the program.

4.2 Assessment of the Utility of WRAP in Developing Naturalized Flows

Based on values obtained in manual calculation and using WRAP-HYD, the created model for WRAP streamflow naturalization worked as expected. The sequences of monthly naturalized streamflow values computed using the program (shown in Appendix 4-1) equalled the figures obtained in the parallel manual calculation for all control points (shown in Appendix 4-2). Their tabulated flow-frequency values are reproduced in Appendix 4-3.

Hydrographs of the monthly naturalized flows and exceedance frequency curves for Oroua River at Almadale and Kiwitea Stream at Spur Road gauging stations covering the 1993-1998 period of analysis are shown in Figures 4-1 and 4-2, respectively. They approximate the flows that would have measured at the gauging stations in the absence of upstream water abstractions and discharges. The corresponding flow-frequency values for the two gauging stations and all water rights locations at 75%, 90%, 95% and 100% time exceedance are shown in Table 4-1 while a more complete list is given in Appendix 4-3. They indicated that throughout the period-of-analysis, at least 1636 lps natural flows at Almadale and 265 lps at Spur Road gauging sites could have occurred at all times. These values are about 79% and 179% higher than the required instream flow requirement at their respective location.

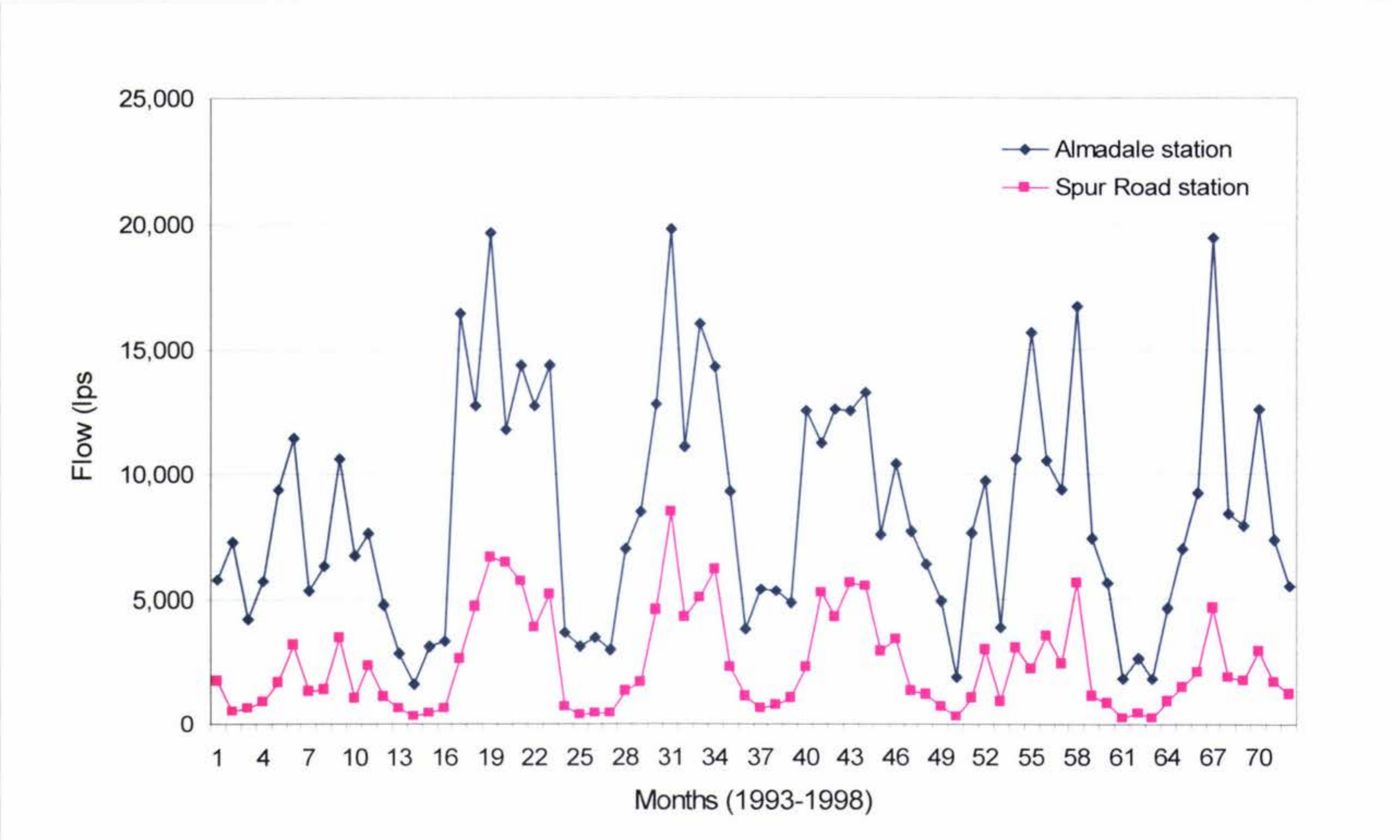
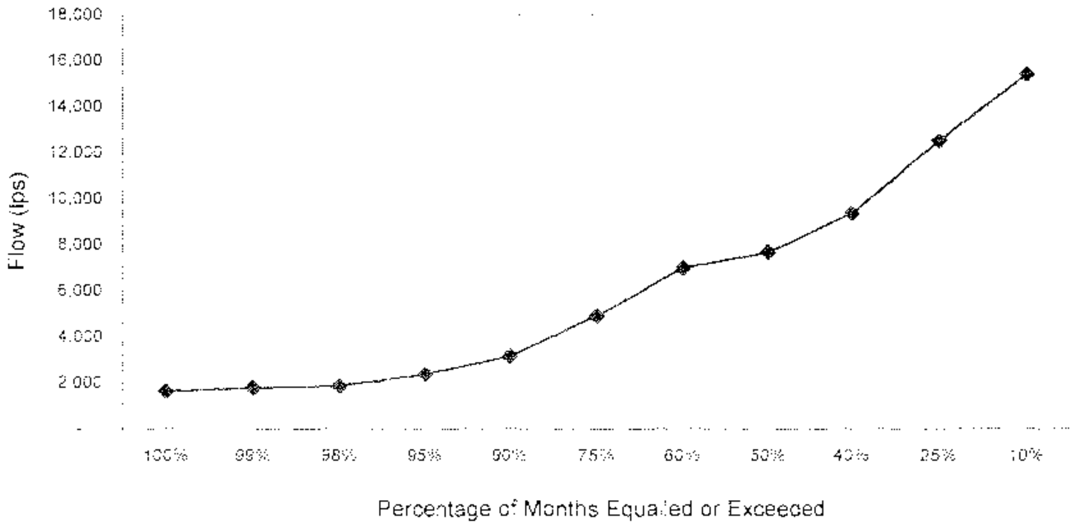
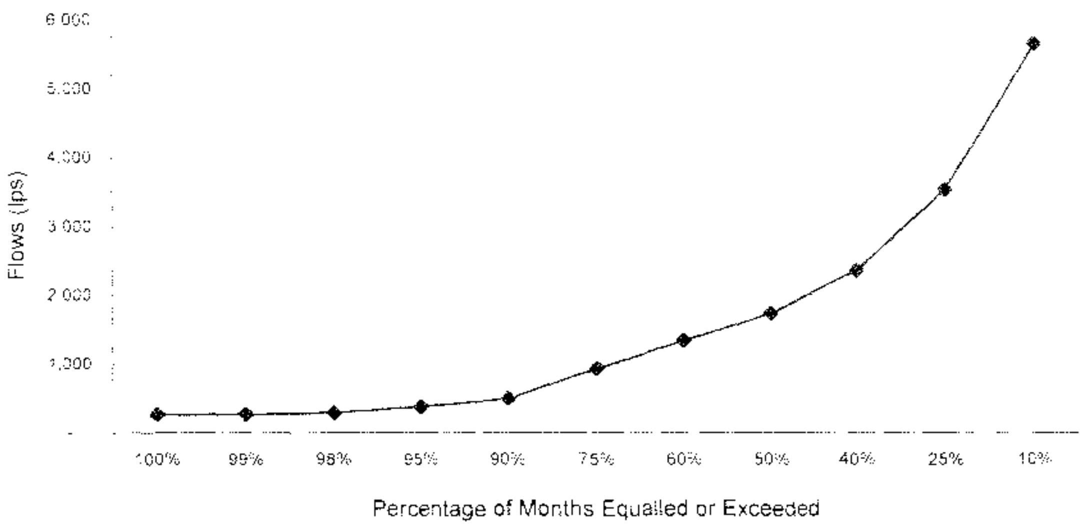


Figure 4-1. Naturalized Flow at the Oroua River



(a)



(b)

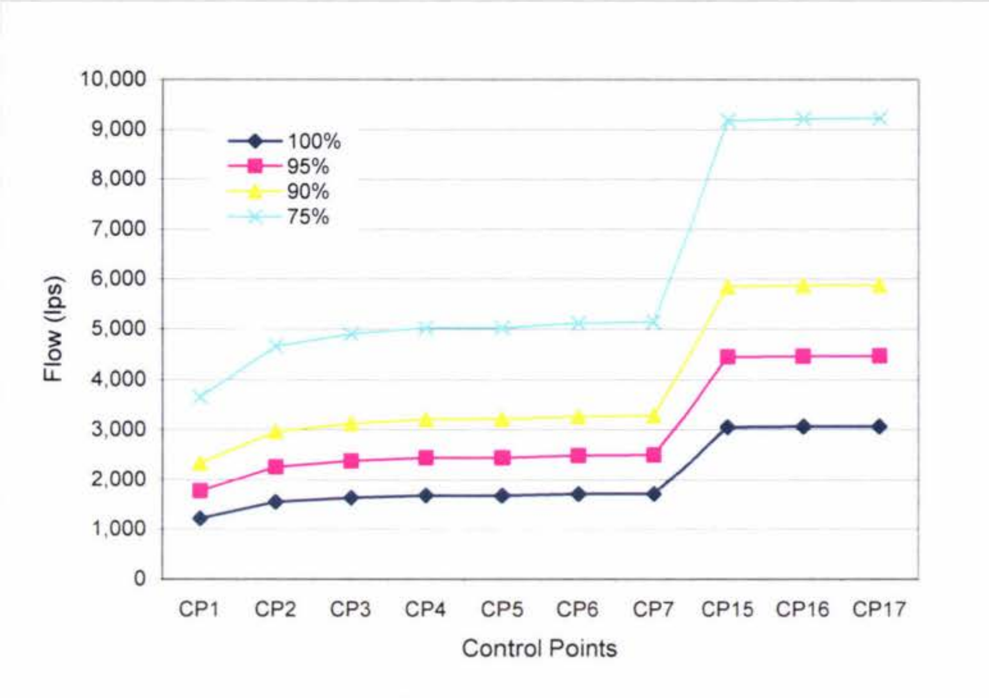
Figure 4-2. Flow-frequency Curves for Oroua River at Almadale Station (a) and Kiwitea Stream at Spur Road Station (b)

Table 4-1. Percentage of Months with Flows Equaling or Exceeding the Values Shown

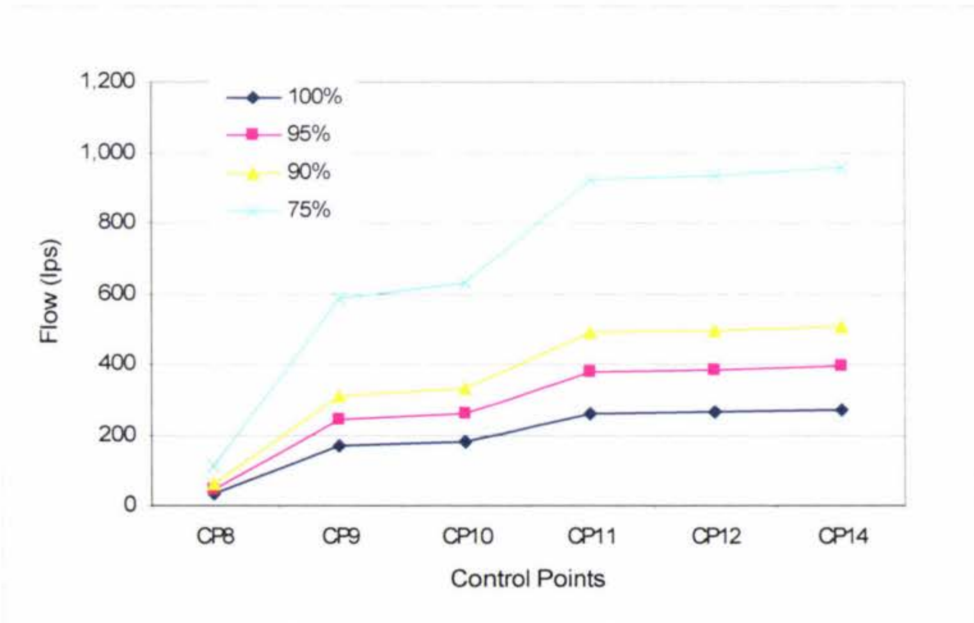
Control Point	100%	95%	90%	75%
Along Oroua River				
CP1	1,218	1,769	2,335	3,661
CP2	1,552	2,254	2,974	4,663
CP3	1,636	2,376	3,135	4,915
CP4	1,679	2,438	3,218	5,044
CP5	1,680	2,440	3,220	5,048
CP6	1,709	2,482	3,275	5,134
CP7	1,719	2,497	3,295	5,165
CP15	3,058	4,441	5,861	9,187
CP16	3,068	4,457	5,881	9,219
CP17	3,073	4,463	5,890	9,232
Along Kiwitea Stream				
CP8	32	47	60	114
CP9	166	241	310	587
CP10	178	259	332	630
CP11	262	379	487	923
CP12	265	385	494	937
CP14	272	394	506	959

*unit in lps

Naturalized flows along Oroua River and Kiwitea Stream equalled or exceeded 75% to 100% of the time are plotted in Figure 4-3. Except at Kiwitea's most upstream water right, the set minimum flows of 915 and 95 lps at Almadale and Spur Road stations, respectively, were exceeded at all associated water rights locations 100% of the time. However, it should be noted that the instream flow requirements for the Oroua River and Kiwitea Stream are presently gauged only at Almadale and Spur Road stations, respectively. They are based on the one-in-five year seven-day low flow observed at these stations. The specific threshold levels at any other locations are not defined.



(a)



(b)

Figure 4-3. Naturalized Flow-Frequency Curve along Oroua River (a) and Kiwitea Stream (b)

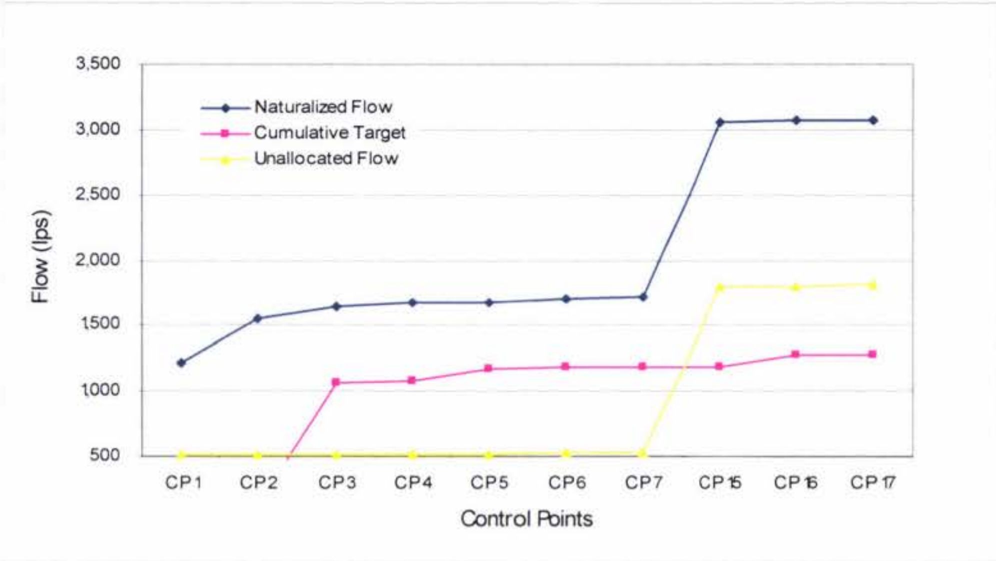
In the case of the Oroua catchment, suspension of rights for irrigation purposes and restriction of those for municipal supply apply when the set minimum flow at their respective gauging stations are reached. Most water right holders in the catchment have not historically used their full permitted abstraction rates at all times. Many abstractions are taken only during a part of a day and uses like irrigation and crop-processing industry are seasonal (MWRC, 1997). However, if existing rights must be protected before issuing new rights, full permitted rates of existing rights and environment need should be assumed occurring at all times.

Table 4-2 and Figure 4-4 compares the combined cumulative permitted abstractions and instream flow requirements with the developed naturalized flows at each water right location along Oroua River and Kiwitea Stream. Since the minimum flow requirements are currently defined only at Almadale and Spur Road stations, a cumulative value would mean applying the minimum flow requirements at downstream rights locations. Such an approach was adopted to account for the set minimum flows in approximating uncommitted or unallocated flows. The combined cumulative abstractions and minimum flow requirements at the gauging stations were below their respective naturalized stream flow 100% of the time. They were, at most, 69% (at CPs 5-7) and 53% (at CP 12) of associated naturalized flows along Oroua River and Kiwitea Stream, respectively. This suggests that, on a monthly basis, there were enough flows to satisfy all consented abstraction rights, including the required minimum flow at Almadale and Spur Road gauging stations and at the downstream rights locations. There were at least 515 lps unallocated or uncommitted flow along Oroua River upstream of the Oroua-Kiwitea confluence. The unallocated flow along Kiwitea Stream is at least 126 lps, except at its most upstream right location. The percent values of unallocated or uncommitted water physically available at each water right location suggest that water use in the Oroua River could be increased. However, it should be noted that such values are only indicative since equivalent threshold levels at ungauged rights locations are presently not defined.

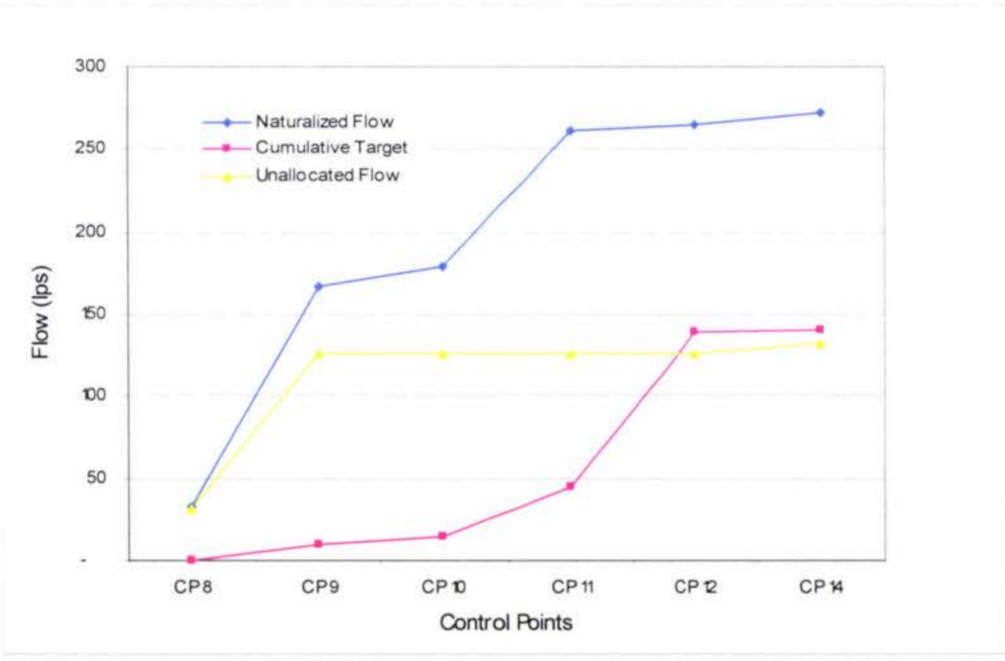
Table 4-2. Naturalized Flow versus Water Rights Target

Control Point	Water Right	Permitted Abstraction	Cumulative Target (Abstraction + IF)	Naturalized Flow	Available Flow	Unallocated Flow total	Unallocated Flow % Available
Along Oroua River							
CP1	WR-MWC902876	30.0	30.0	1,218	1,188	515	43
CP2	WR-100790	104.2	134.2	1,552	1,418	515	36
CP3	WR-4514	7.9	1,068.2	1,636	568	515	91
	Minimum Flow (IF)	915.0					
	WR-3600	11.1					
CP4	WR-3675	15.3	1,083.5	1,679	595	515	87
CP5	WR-4586	81.0	1,164.5	1,680	515	515	100
CP6	WR-4487	6.9	1,185.6	1,709	523	523	100
	WR-4447	14.2					
CP7	WR-MWT820019	3.0	1,188.6	1,719	531	531	100
CP15	WR-6105	2.6	1,191.2	3,058	1,866	1,798	96
CP16	WR-MWT690185	78.9	1,270.1	3,068	1,798	1,798	100
CP17	*none*	0.0	1,270.1	3,073	1,803	1,803	100
Along Kiwitea Stream							
CP8	WR-6092	0.5	0.5	32	32	32	100
CP9	WR-MWC912875	8.9	9.4	166	157	126	80
CP10	WR-MWCT701526	5.0	14.4	178	164	126	77
CP11	WR-6273	30.1	44.5	262	217	126	58
CP12	Minimum Flow (IF)	95.0	139.5	265	126	126	100
CP14	WR-4796	0.3	139.8	272	132	132	100

unit in lps



(a)



(b)

Figure 4-4. Naturalized Flows at 100% Exceedance versus Water Right Requirements and Unallocated Flows along Oroua River (a) and Kiwitea Stream (b)

WRAP facilitated the development of naturalized flows and associated frequency indices using the traditional approach. However, the reliability of naturalized flow estimates depends on the assumptions made with regard to the following: 1) use coefficients of the permitted abstractions and discharges for gauged flow adjustments; 2) sufficiency of drainage area ratio in synthesizing naturalized flows from gauged to ungauged water rights locations; 3) negligible return flows; 4) computational time interval; and 5) repetition of historical period-of-record hydrology. Discussion of the reliability of the naturalized flow estimates is on Section 4.7.1.

4.3 Water Allocation Based on Permitted Rates

Simulation of water allocation based on full permitted rates could be used in assessing hydrologic and institutional water availability and reliability for the existing water rights in the Oroua River for regulatory and water right permitting purposes. On the other hand, modeling based on estimated abstractions could be useful for planning purposes.

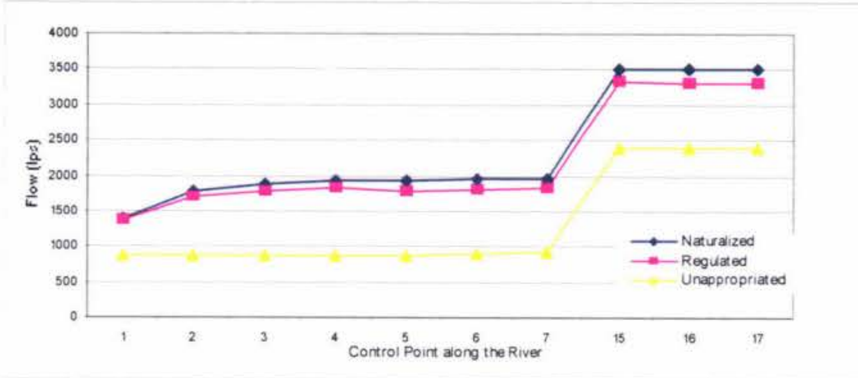
The developed WRAP models for the allocation based on full permitted and estimated abstraction rates worked as intended. Their simulated values of available streamflow and actual diversion for each water right and regulated and unallocated flow for each control point agreed with the values obtained in the sample parallel manual calculation shown in Appendix 4-4. Detailed simulation outputs throughout the period of analysis were not reproduced here. Rather, a reliability summary for meeting the permitted rights and set instream flow requirements is presented in Appendix 4-5.

A reliability summary on meeting water requirements of all rights considered in the study showed that there were enough flows to meet all permitted abstractions and maintain the set minimum flows at the gauging stations and their respective downstream rights locations. On a monthly basis, results of the simulation indicated that there were no diversion shortages experienced by any right and instream flow shortages during the period of analysis.

For the simulation with estimated abstraction scenario, naturalized, regulated, and unallocated flows along the Oroua River and Kiwitea Stream for January and March 1998 were compared in Figures 4-5. January and March 1998 were chosen for discussion since they were the driest months during driest period (1997-1998) on record (NIWA, as cited by

Recile, 1990). Hypothetically, abstractions would be nearest to the permitted rates for these months. Their ratios and averages are tabulated in Table 4-3.

For March, there were at least unallocated flows or water available for additional abstractions of 784 and 2219 lps along Oroua River before and after the confluence, respectively. On the average, unallocated flows along these reaches represented at least 45 and 70 percent of the regulated flows. Except at the most upstream water rights location with still available water of only 32 lps, the still uncommitted flows were from 136 lps before to 142 lps after the Spur Road station. They comprised at least 59 percent of the regulated flows. There was an increase in unallocated flows after the Oroua Kiwitea confluence of 2.4 times its combined unallocated flow before the confluence. In estimating unallocated flows for rights locations downstream of the two gauging stations, flows equal to the set minimum flow at their associated station were allocated for the environment. They were assumed to be the instream flow requirement at the said locations. Flow frequency values for unallocated flows along Oroua River and Kiwitea Stream during the period of analysis are shown in Table 4-4 and Figure 4-6, respectively.



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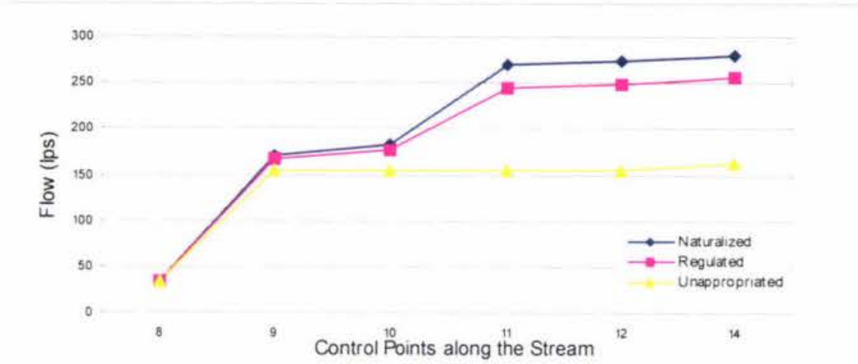

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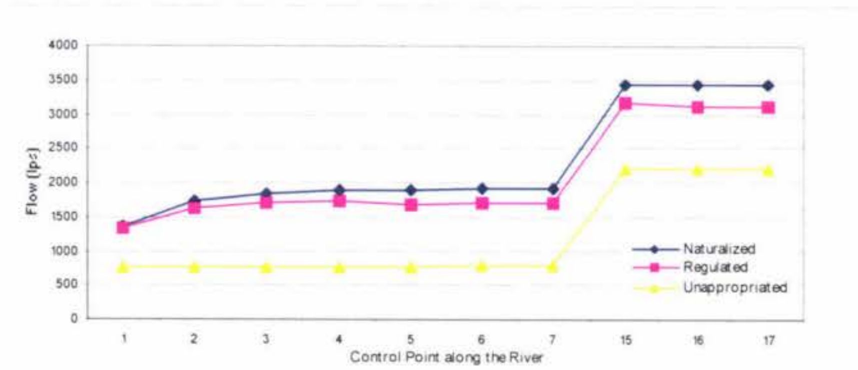

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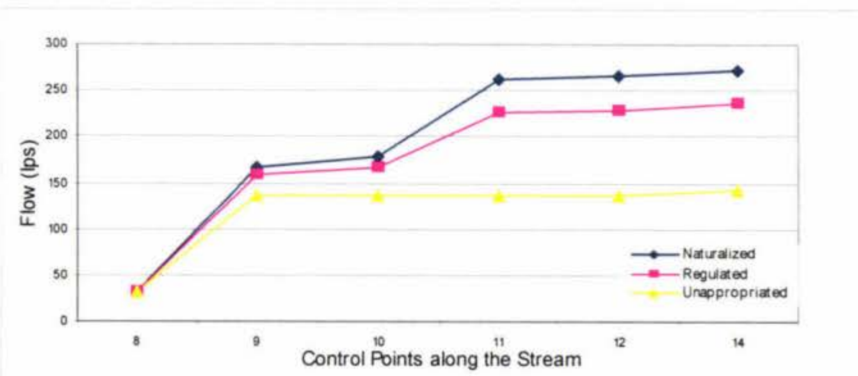


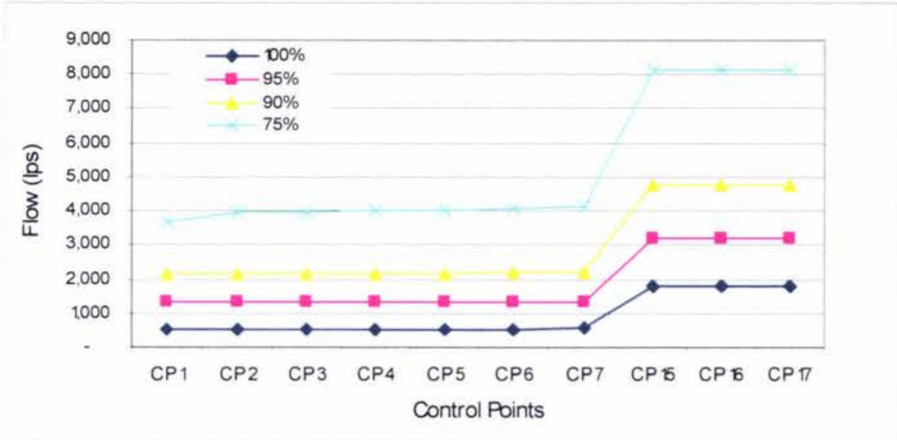
(d)

Figure 4-5. 1998 Streamflow at Almadale for Jan (a) and Mar (c) and at Spur Road for Jan (b) and Mar (d)

Table 4-3. Streamflow Ratios for January and March 1998

Oroua River	January 1998					March 1998				
CP	NF	Reg	Una	Reg/NF	Una/Reg	NF	Reg	Una	Reg/NF	Una/Reg
1	1396	1380	890	0.99	0.65	1366	1342	784	0.98	0.58
2	1779	1705	890	0.96	0.52	1740	1632	784	0.94	0.48
average				0.97	0.58				0.96	0.53
3	1875	1790	890	0.95	0.50	1835	1710	784	0.93	0.46
4	1924	1831	890	0.95	0.49	1883	1746	784	0.93	0.45
5	1925	1788	890	0.93	0.50	1884	1682	784	0.89	0.47
6	1958	1809	911	0.92	0.50	1916	1697	799	0.89	0.47
7	1970	1819	922	0.92	0.51	1928	1706	808	0.88	0.47
average			901	0.94	0.50			792	0.90	0.46
Kiwitea Stream										
8	33	33	33	0.99	1.00	32	32	32	0.98	1.00
9	171	166	156	0.97	0.94	166	159	136	0.94	0.86
10	184	176	156	0.96	0.89	178	167	136	0.92	0.82
11	270	245	156	0.91	0.64	262	226	136	0.82	0.60
12	273	249	156	0.91	0.63	265	229	136	0.83	0.59
14	272	236	162	0.87	0.69	272	236	142	0.83	0.60
average			136	0.93	0.80			120	0.89	0.75
After Oroua-Kiwitea Confluence										
15	3504	3327	2398	0.95	0.72	3429	3169	2219	0.92	0.70
16	3296	3296	2398	1.00	0.73	3441	3117	2219	0.91	0.71
17	3522	3301	2403	0.94	0.73	3446	3122	2224	0.91	0.71
average			2400	1.0	0.7			2221	0.91	0.71
combined average Una flow										
before the confluence:			1037					912		
times increased:			2.31					2.43		
average increase (Jan & Mar):			2.37							

NF – naturalized flow   Reg – regulated flow   Una – unallocated flow



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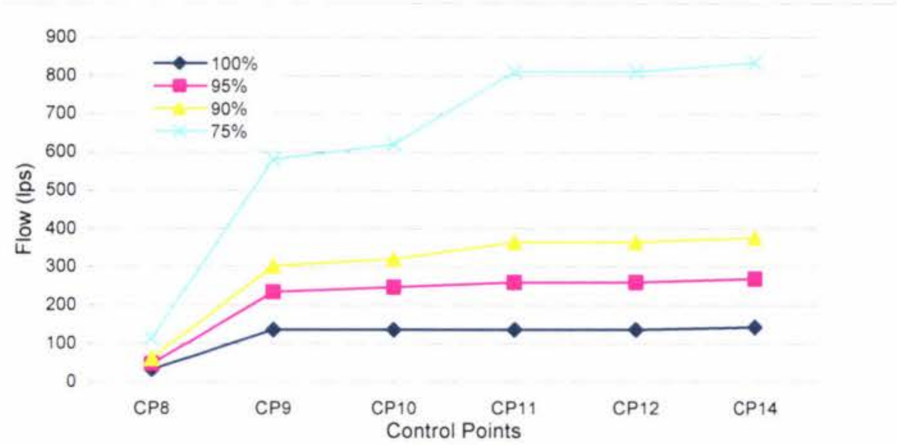


(b)

Figure 4-6. Unallocated Flows along Oroua River (a) and Kiwitea Stream (b)

Table 4-4. Unallocated Flow*-frequency for Percent Time Exceedance

Control Point	100%	95%	90%	75%
CP1	538	1,324	2,145	3,644
CP2	538	1,324	2,145	3,932
CP3	538	1,324	2,145	3,932
CP4	538	1,324	2,170	4,012
CP5	538	1,324	2,170	4,012
CP6	546	1,349	2,210	4,087
CP7	554	1,361	2,228	4,117
CP15	1,779	3,205	4,742	8,101
CP16	1,779	3,205	4,742	8,101
CP17	1,784	3,212	4,750	8,114
CP8	32	47	60	114
CP9	136	234	302	580
CP10	136	247	320	619
CP11	136	259	364	810
CP12	136	259	364	810
CP14	142	269	376	833
*flows in lps				

4.4 Water Allocation During Low River Flows

Water allocation management during low river flows includes: 1) restriction of irrigation abstraction rates based on a monthly flow threshold and 2) suspension of irrigation permits and restriction of abstraction rates for public supply when flows reach the specified minimum levels. Modeling of these water allocation schemes was aimed at identifying their likely impacts in terms of meeting the specified instream flows and existing water right requirements. It could also be used to assess water use efficiency of the allocation schemes. However, an effort to represent the allocation rules during low flows in WRAP-SIM did not achieve the desired model structure. This is due to an apparent inflexibility of the simulation program to model a diversion target that varies as a function of gauged flow at other locations. Below are the related features of WRAP-SIM that were considered and explored in an attempt to model the Oroua catchment allocation scheme, as well as the reasons why they were deemed insufficient or unsuitable to simulate the Oroua catchment allocation rules during low flows.

- Building a Diversion Target

Target Option (TO) record – This record is designed to build a diversion or instream flow target as functions of: naturalized, regulated, or unallocated streamflow; reservoir storage or drawdown; streamflow depletion by other rights; and specified lower and upper bounds (Wurbs, 2000). In the case of the Oroua catchment, diversion targets for municipal, industrial, and irrigation supplies should vary automatically with the flow at its associated gaging station or with the corresponding flow at their location. Though WRAP-SIM allows building a target step-by-step using several TO records, it will adopt only one final target which could be specified as either the maximum or minimum or sum of the target in the last TO record and the preceding cumulative target.

Target Series (TS) record – This record allowed integration of a time series of monthly targets developed outside of the model into the sequential step-by-step WRAP-SIM target building scheme and target variation between years or seasons. Though it allowed modification of diversion requirements computed within the model as a function of streamflow, only either the greater or lesser or summation or product of the result of TO versus TS target was adopted.

- Specifying diversion as a function of a dummy reservoir storage

Drought Index (DI) record – This record, together with its associated drought index storage (IP) and percentage (IS) records, is used to allow instream flow, diversion, and hydropower requirements to vary with reservoir storage content. An attempt to model the instream flow requirements, as storage content of a dummy reservoir to be later drained using the empty function option, was unsuccessful. Inputting flow percentages on the IP and IS records, wherein rights restrictions and suspensions take effect, allowed modeling of the allocation scheme during low river flows. However, the empty function of DI record had the effect of losing from the system the water in the dummy reservoirs instead of draining its contents back to the river system.

- Specifying system operating rules

ML record – This record allowed monthly varying limits of streamflow depletion to be imposed on a right. Months when river flows are likely to fall to the specified thresholds were identified. However, restrictions on rate of abstractions only apply once the specified monthly flow thresholds are reached and cease as soon as the river flow goes above those thresholds. Moreover, restrictions for irrigation-related diversions apply to their combined abstractions and not on individual rights.

- Control Point Assignment

CP record – This record allowed grouping of multiple water rights situated along a specified reach by associating the rights with the same control point. This could facilitate modeling the combined maximum abstraction rates for the purpose of irrigation during months with set flow thresholds. However, rights' access to streamflow available at the control point is ranked in priority, which is not entirely the case for Oroua River water allocation management.

4.5 Modified Simulation Run for Allocations Based on Low River Flows

The simulation program did not have a mechanism to automatically trigger a change in diversion targets whenever the flow fluctuates about a specified level. The WRAP model built for allocation based on permitted rates was revised to adopt the new set of diversion targets as defined by the rule on maximum abstraction rates at times of low river flows and by the set minimum flows. Such revisions were made to simulate the capability of the monthly flow threshold and minimum flow allocation schemes to prevent or minimize shortages in meeting the instream flow requirements or free-up water for environmental needs.

The stipulated combined maximum abstraction rates for irrigation-related rights held prior to 21 April 1994 and suspension of similar rights held after the said date when flow reached a specified threshold were modeled through the water right (WR) record. The new diversion targets were set according to the maximum abstraction rates of 50 lps when flow for Oroua River at Almadale station is 1015 lps; and 20 lps when flow for Kiwitea at Spur Road station is 300 lps. These maximum rate values were used since these are the lowest flow levels where irrigation abstractions are still allowed. The no-net-effect-on-flow rule for water right 690185 held by Manawatu Beef Packers Ltd. could be modeled by specifying a 100 percent return flow in its associated water right (WR) record. However, it was assumed deferred in simulating allocation based on monthly flow thresholds to investigate possible impact of unrestricted abstraction by the said right. Similarly, the new diversion targets from rate restrictions and rights suspension defined by minimum flows were modified the same way. The permitted abstractions for the purpose of irrigation and for water right 690185 were set equal to zero for this simulation scenario. The modified WRAP models for these simulation scenarios are shown in Appendix 4-6.

Simulation output for regulated and unallocated flows matched the values obtained in the sample manual calculation (shown in Appendix 4-7), suggesting that the WRAP models built behaved as expected.

4.6 Data Requirements for WRAP Modeling

4.6.1 Streamflow and Water Use Records

Like any other water balance studies or volume accounting computations, simulation of water hydrologic and institutional availability is beset with the problem of estimating different water flow components – such as return flows and actual water use. WRAP simulation starts with known naturalized flows, either provided as input or computed within the program. Thus, accuracy of the simulated available, regulated, and unallocated flows and water rights and instream flow shortages largely depends on the reliability of the input data for naturalized flow determination. Moreover, estimation of reliability and flow-frequency values is based on the premise of repetition of historical hydrology represented by naturalized flows.

Developing naturalized streamflows typically represents a major part of the water availability modeling work (Wurbs, 2000). The extent to which observed flows are naturalized is based largely on judgement. Quantifying and removing all deviations from natural flow condition might not always be possible especially in the absence or scarcity of reliable data. Usually, at least 40 year period-of-record (POR) is used for streamflow naturalization using the traditional approach (TNRCC, 1997); while a 30 to 80-year period-of-analysis would be more representative of actual WRAP modeling application.

The major problems encountered in the case of the Oroua River basin were: lack of actual water use data for almost all abstraction and discharge rights; unknown return flows from irrigation-related rights; presence of data gaps; short overlap of PORs at past and existing gauging stations; and, ungauged outflows leaving no base to check the results of the simulation. Synthesizing naturalized flows at ungauged water rights locations ideally requires information on watershed characteristics such as land use, precipitation, and drainage area associated with each water right. Problems with the required data were more concerned on the accuracy and reliability of the estimates rather than on the utility of WRAP as a water availability assessment and management tool.

4.6.2 Computational Time Interval

Though the WRAP model had provision for variations in water use targets, the current version uses a monthly computational interval – monthly data. However, Recile (1999) noted that the use of monthly streamflow data may not correctly reflect the real flow situation in the Oroua River since monthly values assumed a uniform flow distribution throughout the month. A check of the actual daily flow records for Oroua at Almadale in February 1998 (shown in Appendix 4-8) indicated that monthly data masked the generally less than 2000 lps daily flows by a flood event of about 18030 lps that happened at the later part of the month. Though the flood event lasted for several hours only, it increased the monthly average streamflow by about 6 m^3/s (MWRC, as cited by Recile, 1999). The hydrographs shown in Appendix 4-8 further illustrate that flood events could increase the monthly flow estimates considerably.

A shorter time-step of weekly or daily would be more useful in the relatively small and narrow catchment of Oroua River where the water use and allocation management is defined by the specified flow levels observed at certain gauging stations. There is provision to revise the monthly computational time interval. However, significant modifications to the Fortran programs would be required to change to other time steps such as weekly or daily (Wurbs, 20001).

4.7 Reliability of the Simulation Results

This section discusses the reliability of the estimated naturalized streamflows, the validity of the flow distribution method used, and the simulation output for regulated, available, and unallocated flows.

4.7.1 Naturalized Streamflows at the Gauged Sites

The river-basin hydrology for the part of the Oroua catchment considered in this study was represented in WRAP by naturalized streamflows. In general, naturalized streamflow estimates are not assessed in terms of accuracy because their true value is hardly known, leaving no base for comparison with the computed or simulated value.

A review of literature and personal inquiry with MWRC yielded no previous naturalized flow estimates for Oroua Catchment.

In establishing the best estimates of naturalized flow, one suggested approach is a comparative naturalized flow determination using other methods (TNRCC, 2000). This however, was beyond the scope of this study and was put forward as an area for future research.

4.7.2 Drainage Area Ratio as a Distribution Method

The drainage area ratio method used in transposing naturalized flows from gauged to all ungauged control points or water rights locations was based on the premise that flows at each control point were in constant proportion to ratios of watershed parameters. In this case, the watershed parameter is the drainage area. Linear regression and correlation techniques and flow analysis ratio at pairs of stations could facilitate evaluation on the naturalized flows distributed by the chosen method. Setting the y-intercept equal to zero would obtain a regression model where flow at a station is expressed simply as constant times the flow on another station. The slope coefficient m determined by the zero-intercept $(b=0)$ linear regression could be related to drainage areas (TNRCC, 1999). Theoretically, a high correlation coefficient for a pair of stations would be associated with relatively small difference in drainage areas.

In flow ratio analysis, the basic concept was to evaluate the capabilities for predicting naturalized flows at subcatchments ($Q_{subcatchment}$) from assumed known flows from larger catchment ($Q_{catchment}$) based on the relationship, $Q_{subcatchment} = C\ Q_{catchment}$, or distribution of flows in proportion to ratios of watershed parameters C. The naturalized flow ratios for pair station were normalized by dividing their respective drainage areas. These flow ratios would all be 1.00 if flows were strictly proportional to drainage area (TNRCC, 1999).

In the case of Oroua catchment, there were insufficient stations to allow a more conclusive analysis. There was only one existing gauging station along the main reach and one along the Kiwitea Stream. To have a gauge on the validity of drainage area ratio method in distributing flow within the study area, the analysis made use of a 1993-1998 series of naturalized flows for the old Kawa Wool station located downstream of the Oroua River-Kiwitea Stream confluence. The "regression" naturalized flow series for the old Kawa Wool plotted in Figure 4-7 was developed using a set of regulated flows generated based on concurrent flows at Almadale station as described in the Methodology – Section 5.5. The prediction equation determined from categorical regression was: Kawa = (Almadale – 38.904 – (trans2_1*46.038)) /0.7430, wherein trans2_1 is the quantification of month (Appendix 4-9). The coefficient of determination (R^2) was 0.947. The WRAP-synthesized naturalized flow for the old Kawa Wool station is also plotted in Figure 4-7.

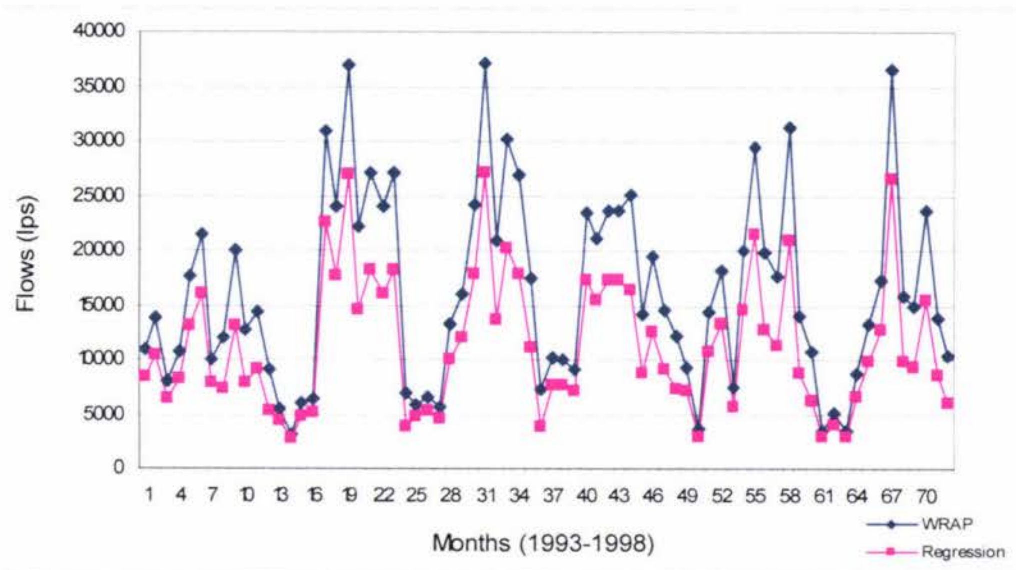


Figure 4-7. Predicted Naturalized Flows for the Old Kawa Wool Station

Linear regression coefficients and flow ratios for stations in the study area are summarized in Tables 4-5 and 4-6, respectively. The complete monthly flow ratio values for the whole period-of-analysis are shown in Appendix 4-10. Results of regression and correlation analyses showed an essentially linear relationship for pairs of stations. In general, the flow ratio varies significantly between months at any station, indicating that *C* is not constant for monthly flows at any stations. Varying C values between months would suggest that the flow for an individual month cannot be predicted reliably regardless of watershed parameters or form of the relation used to determine C. Adopting a modified nonlinear form of the basic relationship between flows at different locations, such as $Q_{subcatchment} = C\ (Q_{catchment})^N$, would provide little or no improvement in predictive capabilities (TNRCC, 1999).

Comparison of the slope coefficient *m* and drainage area ratio could provide a measure of the validity of the drainage area ratio approach as a method for predicting the mean naturalized flow at one location given the flow at another location. The slope *m* would be equal the drainage area ratio if the distribution method used worked perfectly. Using the naturalized flow developed based on predicted flow for the old Kawa Wool showed variations with *m* and drainage area ratios, suggesting a possible inadequacy of the method in the portion of Oroua catchment studied.

The validity of the above findings depended on the validity of the assumptions made in developing the naturalized flows, mainly on the equation used to generate flows that were measured at the old Kawa Wool station and on the estimates of abstractions and discharges that might have occurred during the period-of-analysis.

Table 4-5. Linear Regression Coefficients for Stations in Oroua Catchment

Stations	R	R^2	y-intercept* (b)	Slope (m)
Spur vs. Kawa Wool**	0.862	0.743	-0.2954	0.6605
	0.846	0.716	0.0	0.550
Spur vs. Almadale	0.882	0.778	-0.343	0.477
	0.862	0.742	0.0	0.387
Almadale vs. Kawa Wool**	0.990	0.980	0.068	1.402
	0.989	0.979	0.0	1.428

*y-intercept in in/mo

Table 4-6. Flow Ratios for Stations in Oroua Catchment.

Station Pair	Drainage Area Ratio	Flow Ratio mean	min	Max
Spur/Kawa Wool **	0.417	0.47	0.122	1.069
Almadale/Kawa Wool**	0.532	1.43	1.14	1.89

** flow series based on regression

4.7.3 Regulated, Available, and Unallocated Flows

Generally, simulation outputs such as available water and unallocated flows at a location are not assessed in terms of accuracy or reliability of estimates because they are best estimates only, at least for those that incorporate a priority system. There are no actual data to be matched. Moreover, actual abstractions rarely match the permitted abstraction rates.

The simulation showed that there were enough flows in the river and stream to meet the water requirements of the existing rights on a monthly basis. However, this might not be the case on a shorter time basis, such as weekly or daily, mainly because the simulation was based on a monthly data and computational interval. The use of monthly streamflow estimates could be misleading since it assumes a uniform flow throughout the month. Any flood event that occurred within a short time could increase the monthly flow value, making it appear as if there was enough streamflow available for abstractions.

4.8 Alternative Water Management Scenarios

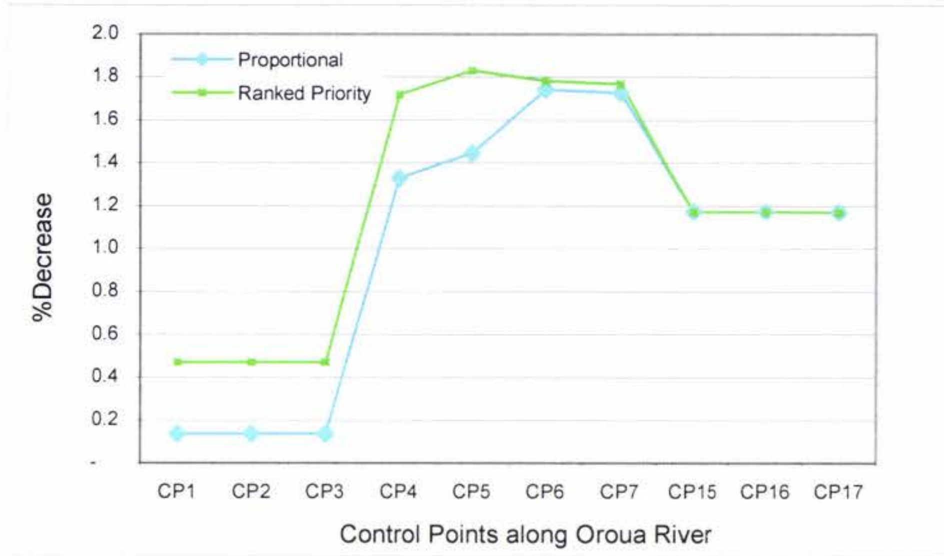
Two alternative management scenarios were simulated to identify possible directions to develop an alternative allocation scheme for the Oroua River. They focused on apportioning the allowed combined maximum abstraction rates for irrigation. One allocated the remaining fraction of the combined rates proportionately among irrigation-related rights granted after 21 April 1994 based on their full permitted rates. The other used a ranked priority scheme to allocate the combined maximum abstraction rates among irrigators. This section compared the unallocated flows estimated in alternative allocation scenarios with those obtained in the allocation based on monthly flow threshold. In the latter allocation scheme, the combined maximum rates rule for the purpose of irrigation applies. Irrigation-related rights granted after 21 April 1994 are curtailed whenever the monthly flow threshold are reached at their associated station. The analysis focused on the unallocated flow since it is the output parameter that could indicate level of efficiency of an allocation scheme in terms of utilizing the available water. Unallocated flow is the amount of flow still uncommitted after all water rights including instream needs are met. It represents water available for new water right applicants. A decrease on unallocated flow would mean an increase in diversion of available water that, otherwise, flows out of the river system unutilized. The discussion below made use of the February 1998 values.

The unallocated flows for the two alternative scenarios are compared with those obtained for the allocation based on monthly flow thresholds in Table 4-7. In general, percent decreases of unallocated flow (plotted in Figure 4-8) that resulted from proportionally apportioning the unused percentage of the combined maximum abstraction rates among "recent" irrigation-related rights were minimal. They ranged from 0.1 to 1.7 and 0.1 to 3.8 percent along the Oroua River and Kiwitea Stream, respectively. As expected, relatively higher percent decreases were computed for locations with associated "recent" irrigation-related rights (that is, from CPs 4 to 17 and 11 to 14).

Similarly, percent decreases of unallocated flows from ranked priority allocation of the remaining flow under the combined maximum abstraction rule were also minimal and followed basically the same trend. Though values for CPs 1, 2, 3 and 8 were 0.4 percent higher from those with the proportional allocation scheme, the difference is at most 0.1 percent for remaining control points.

Table 4-7. Unallocated Flows (UNA) for February 1998 for the Proportional and Ranked Priority Allocation Schemes for the Combined Maximum Abstraction Rates for Irrigation-related Rights

Control Points	Monthly Flow Thresholds	Proportional Allocation UNA	Proportional Allocation % decrease	Ranked Priority UNA	Ranked Priority % decrease
Along Oroua					
CP1	1,643	1,640	0.1	1,635	0.5
CP2	1,643	1,640	0.1	1,635	0.5
CP3	1,643	1,640	0.1	1,635	0.5
CP4	1,698	1,676	1.3	1,669	1.7
CP5	1,700	1,676	1.4	1,669	1.8
CP6	1,747	1,717	1.7	1,716	1.8
CP7	1,761	1,731	1.7	1,730	1.8
CP15	3,883	3,837	1.2	3,837	1.2
CP16	3,883	3,837	1.2	3,837	1.2
CP17	3,890	3,845	1.2	3,845	1.2
Along Kiwitea					
CP8	60	60	0.4	60	0.8
CP9	300	300	0.1	300	0.2
CP10	317	317	0.1	317	0.1
CP11	386	371	3.8	371	3.7
CP12	386	371	3.8	371	3.7
CP14	398	383	3.6	383	3.6



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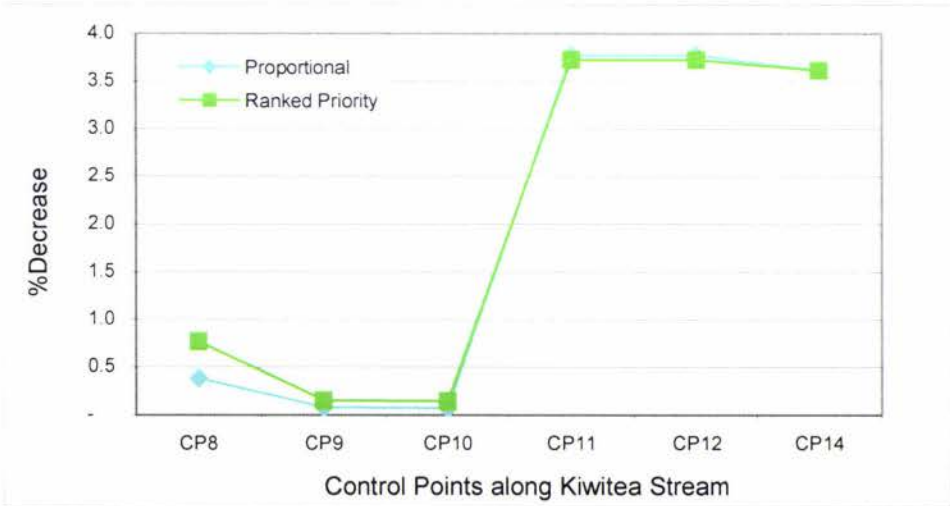

(b)

Figure 4-8. Changes of Unallocated Flows from the Monthly Flow Threshold Allocation along Oroua River (a) and along Kiwitea Stream (b)

The simulated unallocated flows for the two alternative allocation scenarios showed minimal percent decrease of unallocated flows from the values obtained with the allocation based on monthly flow thresholds. This implied that the alternative allocation schemes provided little improvement in increasing water use efficiency. One possible explanation for this minimal improvement was the fact that the two alternative schemes only dealt with apportioning the allowed combined maximum abstraction for the purpose of irrigation.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The 1993-1998 natural flows for Kiwitea Stream and Oroua River upstream of old Kawa Wool station were estimated. It could represent the baseline condition for allocating water in this part of the catchment. Available and uncommitted flows at each water right locations were estimated based on the estimated natural flows.

The study demonstrated that water availability modeling could be a useful tool in the Oroua River management context. It could be used in the evaluation of additional water right permit application in the Oroua catchment. Based on the results of the simulation, there was enough flow physically available to meet the existing rights including set minimum flows in the delineated study area for the 1993-1998 simulation period.

For the case of the Oroua catchment, the relevance of WRAP was limited by the program's apparent lack of features or mechanism to support modeling of the current surface water management practice during low river flows. Program modification to include an algorithm that changes diversion target as a function of gauged flow at some locations was required to enhance WRAP's utility. The Target Option (TO) and Drought Index (DO) records were identified as promising routes to achieve the desired feature.

The study demonstrated that the criteria stipulated in the OCWA Regional Plan for rostering abstractions during low river flow could be accounted using the weighted ranked priority scheme. Results of the simulation indicated that allocation schemes based on apportioning the allowed combined maximum abstraction for the purpose of irrigation did not increase the water use efficiency in the catchment significantly. They offered very minimal improvement in the utilization of available water.

5.2 Recommendations

Adaptive modifications to WRAP need to be done to improve its relevance to the water management and planning for the Oroua catchment. One is to include algorithms that vary diversion target as a function of gauged streamflow level at certain locations. The desired feature is quite similar to the DI record that allows diversion, instream flow, and hydropower requirements to vary as a function of reservoir storage. Another modification needed is in the simulation time interval. Shorter time steps, such weekly or daily, would be more appropriate for a small catchment like the Oroua.

There is a need to acquire data on actual abstractions, discharges, and other return flows to the Oroua River and its tributaries, both for compliance and modeling purposes. For future simulation or modeling studies for the Oroua River, there is a need to have an actual streamflow measurement or a gauging station downstream of the river for validation purposes. It is recommended that a comparative naturalized flow determination using other methods (e.g., statistical and rainfall-runoff) be conducted to help establish a reliable estimate of a naturalized streamflow for the Oroua River and its pertinent tributaries.

Appendix 3-1. Evaluated Water Availability Models (TNRCC, 1998)

Hydrologic Model	Developer
Water Rights Analysis Package (WRAP)	Texas A&M University
HEC-PREPRO	
South_Central Trans Texas	HDR
River Basin Network Simulation Model (MODSIM)	Colorado State University
Power and Reservoir System Model (PRSYM)	University of Colorado's CADWEB
Boyle Engineering's Stream Simulation Model (BESTSM)	Boyle Engineering
Stream Simulation Model, State of Colorado (STATEMOD)	State of Colorado
Hydrological Simulation Program-FORTRAN (HSPF)	United States Environment and Protection Agency (EPA) USGS
HEC5	United States Army Corps of Engineer (US COE)
Streamflow Synthesis and Reservoir Regulation (SSARR)	United States Army Corps of Engineer (US COE)
Interactive River Simulation Program (IRSP)	Cornell University
River Simulation System (RSS)	
Massachusetts Insititure of Technology Simulation Model (MITSIM)	Massachusetts Institute of Technology
MIKE BASIN	Danish Hydraulic Institute (DHI)
Soil and Water Assessment Tool (SWAT)	United States Department of Agriculture (USDA)
OASIS with OCL	
WEAP	
DWRSIM	California Department of Water Resources
Aquarius	GE Diaz Dept of Civil Engineering, Colorado State University
Waterware	

Model Assessment Criteria

- Water Rights Criteria
  - Priority System
  - Special Conditions
  - Aggregation/Disaggregation
- Functionality Criteria
  - Channel losses/gains
  - Return flows/water reuse
  - Instream flows
  - Bay & estuary inflows
  - Water allocation
  - Ground water interaction
  - Water quality
- Operational Criteria
  - SB1 Timeliness
  - Performance/accuracy
  - Time step
  - Stochastic Capability
  - Experience
  - Flexibility
  - Costs
  - Ease of use
- Information Technology
  - Ownership
  - Database linking potential
  - Source code modifications
  - GIS compatibility
  - Documentation
  - Ease of upgrading
  - Software/hardware compatibility

Appendix 3-2

RELEVANT INFORMATION ON THE OROUA RIVER CATCHMENT

The Oroua River is on of the tributaries of the Manawatu River. The Oroua River Catchment (shown in Figure A-1) has a total area of 900 square kilometers. Much of the catchment water yield comes from its mountainland watershed. It is estimated that the 10% of the catchment covered by Ruahine State Forest Parks provides approximately 80% of low flows of the river. During low flow periods, tributary flow is extremely limited especially in area with underlying free draining soils where most of the streams are ephemeral and have a low water yield. These streams do not provide any significant low flow to the Oroua River.

Catchment Hydrology

Hydrological data has been collected in the Oroua Catchment at the following sites: 1) Oroua River at Almadale between 1954 and 1979 and again from 1992 to 1999; 2) Oroua River at Kawa Wool between 1967 and 1992; 3) Kiwitea Stream at Spur Road between 1977 and 1999; Kiwitea Stream at Gun Club from 1998; and Makino Stream at Boness Road from 1992 to 1999.

The Kawa Wool hydrological station, situated approximately 500 meters downstream of Aorangi Road Bridge at Feilding, was washed away in flood in July 1992. The new long-term site has since been established at the Almadale Reserve upstream of the confluence with the Kiwitea Stream and major abstractions from the river. The Spur Road station for Kiwitea Stream was lost following a flood event in October 1998. A replacement site was established on the Kiwitea Stream at the Gun Club upstream of the Haynes Creek confluence. A summary of hydrological flow information collected at recording sites on the Oroua River and Kiwitea and Makino Streams is shown in Table A-1.

Figure A-1. The Oroua River Catchment showing is major tributaries, the Kiwitea and Makino Streams (Source: MWRC, 2000)

Table A-1. Summary of Flow Data (in lps) for recording sites in the Oroua River, Kiwitea Stream, and Makino Streams (MWRC, 2000)

	Oroua River at Almadale	Oroua River at Almadale	Kiwitea Stream at Spur Road	Makino Stream at Boness Road
Catchment Area (km^2)	293	293	246	138.8
Map Reference	T23:366 113	T23:366 113	T23:325 101	S23:254 023
Period of Record	1955-99 (gap: 1979-92)	1992-99	1977-99	1992-99 (gap: 27/1-1/2/1999 and 8/3-9/3/1999
Minimum expected flow (instantaneous)				
Annual		920	110	75
Once in 10 years		545	60	55
Expected 1 day flow flow				
Annual		955	120	75
Once in 10 years		580	65	60
Expected 7 day low flow				
Annual		1095	140	80
Once in 5 years		850	100	70
Once in 10 years		720	80	65
Mean Flows				
Annual	10266	8567	2260	824
Autumn (Mar-May)	7235	6559	1299	332
Winter (Jun-Aug)	16603	12298	4030	1768
Spring (Sep-Nov)	11420	9626	2957	1180
Summer (Dec-Feb)	5797	4712	768	276
Flow Duration (Percentage of time flow equals or exceeds)				
Half median flow	3416	3177	500	116
50%	6832	6353	1000	231
80%	2724	2856	338	131
90%	1772	1977	220	105
95%	1322	1534	165	89
96%	1238	1414	154	85
98%	1052	1194	125	77
99%	905	1080	104	72

Note: Oroua River flow below Feilding is influence by water abstraction. This impact is particularly noticeable at low flows. The historical extent of these abstractions is largely unknown. The Almadale flow record has been 'modified' to reflet the change of location for the water abstraction for Feilding's water supply. The abstraction site was transferred form Barrows Rd to Almadale (downstream of the hydrological station) from July 94 to October 1996. The Almadale record is therefore the 'best estimate' of actual flows at the site for this period.

Surface Water Demands

Most of the water abstractions are concentrated in the middle reaches of the catchment between Almadale and Awahuri. The location of major abstractions (those permitted to take over 500 m^3/day is shown in Figure A-2. The high demand for water has to be met largely from surface water because of the poor quality and inadequacy of groundwater supplies especially around the Feilding area.

Water user groups include those taking for stock and domestic use, town and rural supplies, crop and pasture irrigation. They could potentially reduce the Oroua River flow by 433 lps if all consent holders exercised their permits at the same time. This allocation converts to 45 percent of the one-day annual low flow at Almadale.

Aggregate quantities of surface water that are permitted to be taken for various uses under existing resource consents are shown in Table A-2. Abstractors may take the quantities up to a specified limit, and at a rate specified by conditions on their water permit. Many abstractions are only exercised for part days. Details on abstraction rights as well as discharge rights are shown in Table A-3.

Table A-2. Surface water abstractions allowed under existing resource consents, (as of December 1999).

	m^3/day	lps (if taken continously)
Oroua River		
Manawatu District Council (Feilding Water Supply)	9000	104
Kiwitea Rural Water Supply	2592	30
Oroua Rural Water Supply	1008	12
Manawatu Beef Packers Ltd.	6819	79
Irrigators (8)	12017	139
Kiwitea Stream		
Waituna West Water Supply	778	9
Irrigators (3)	3061	35
Makino and Manganoe West Streams		
Irrigators	2120	25

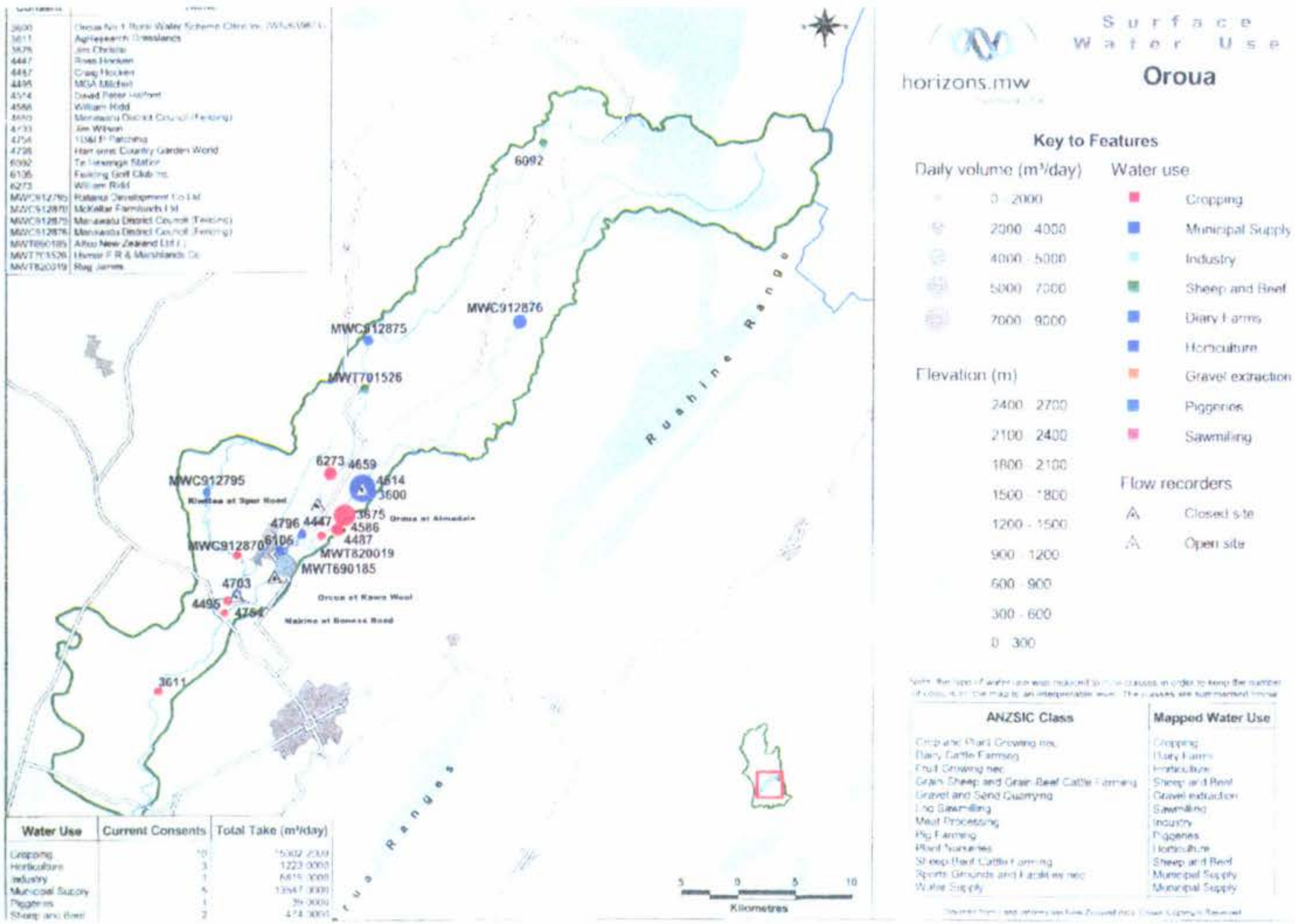

Figure A-2. Surface Water Abstractions in the Oroua River Catchment (MWRC, 2000)

Appendix 3-2. Information on the Existing Water Rights in the Delineated Study Area of the Oroua River Catchment*(MWRC, through personnal communication)

Consent No.	River/Stream	Map Reference	Discharge	Takes/Purpose		Consent Volume (m^3/day)	ANZIC Class	Effective Dates	Holder
Along Oroua River									
MWC912876	Oroua	T23: 502-254		✔	Water Supply	2592	Water Supply	31/08/1992 - 31/08/2012	MDC/Feilding
6096	Oroua	T23: 483-231	✔			216	Sewerage and Drainage Service	19/02/1996 - 26/01/2006	MDC/Feilding
100790	Oroua	T23: 422-156		✔	Water Supply	9000	Water Supply	31/07/2000 - 10/07/2005	MDC/Feilding
4514	Oroua	T23: 366-114		✔	Irrigation	682	Fruit Growing nec	12/07/1995 - 21/06/2005	David Peter Halford
Oroua at Almadale gaging station at T23: 366-113									
3600	Oroua	T23: 364-113		✔	Water Supply	960	Water Supply	15/06/1993 - 30/06/2004	Oroua 1 Rural Water Scheme
4659	Oroua	T23: 364-113		✔	Water Supply	9000	Water Supply	17/07/1995 - 26/06/2005	MDC/Feilding
3675	Oroua	T23: 347-092		✔	Irrigation	1320	Crop & Plant Growing nec	08/07/1993 - 30/06/2004	Jim Christie
4586	Oroua	T23: 348-089		✔	Irrigation	7000	Crop & Plant Growing nec	17/01/1996 - 30/12/2004	William Ridd
4487	Oroua	T23: 343-075		✔	Irrigation	600	Crop & Plant Growing nec	05/02/1996 - 30/12/2004	Craig Hocken
4447	Oroua	T23: 341-077		✔	Irrigation	1225	Crop & Plant Growing nec	07/02/1996 - 30/12/2004	Ross Hocken
MWT820019	Oroua	T23: 328-072		✔	Irrigation	259.2	Crop & Plant Growing nec	31/03/1991 - 01/10/2001	Reg James
Along Kiwitea Stream									
6092	Kiwitea	T23: 522-406		✔	Irrigation	42	Sheep-Beef Cattle Farming	01/12/1995 - 10/11/2004	Te Hekenga Station
MWC912875	Kiwitea	T23: 369-239		✔	Water Supply	768	Water Supply	31/08/1992 - 31/08/2012	MDC/Feilding
MWT701526	Kiwitea	T23: 366-197		✔	Irrigation	432	Sheep-Beef Cattle Farming	09/04/1976 - 01/10/2001	Usmar FR & Marshlands Co.
5071	Chetelham Stream	T23: 437-199	✔			20	Dairy Cattle Farming	30/06/1995 - 09/06/2005	IW Scott & Sons
6273	Kiwitea	T23: 336-124		✔	Irrigation	2600	Crop & Plant Growing nec	05/02/1996 - 30/06/2004	William Ridd
Kiwitea at Spur Road gaging station at T23: 437-199									
4788	Kiwitea	T23: 219-083	✔			7	Dairy Cattle Farming	19/01/1995 - 02/12/2004	Mills DL & EME
4796	Kiwitea	T23: 311-074		✔	Irrigation	29	Plant Nurseries	18/12/1995 - 30/06/2004	Harrisons Country Garden World
Oroua River-Kiwitea Stream Confluence at T23: 308-066									
MWC912775	Oroua	S23: 298-064	✔			40	Prefabricated Metal Building Mfg	11/08/1992 - 30/07/2002	Higgins Contractors Ltd
6105	Oroua	S23:291-060		✔	Irrigation	227	Sports Grounds & Facilities nec	05/12/1995 - 14/11/2004	Feilding Golf Club Inc
4337	Oroua	T23: 305-056	✔			36	Dairy Cattle	27/05/1994 - 06/05/2009	Guy BR
4222	Oroua	S23: 298-049	✔			100	Meat Processing	05/06/1996 - 14/05/2011	Affco New Zealand Ltd
4219	Oroua	S23: 298-048	✔			2000	Meat Processing	05/06/1996 - 14/05/2011	Affco New Zealand Ltd
4220	Oroua	S23: 298-047	✔			8400	Meat Processing	05/06/1996 - 14/05/2011	Affco New Zealand Ltd
MWT690185	Oroua	S23: 297-047		✔	Industry	6819	Meat Processing	28/03/1969 - 01/10/2001	Affco New Zealand Ltd
4223	Oroua	S23: 297-046	✔			1495	Meat Processing	05/06/1996 - 14/05/2011	Affco New Zealand Ltd
MWC912862	Oroua	S23: 293-028	✔			19	Dairy Cattle Farming	22/09/1992 - 30/09/2007	Baxter J
Oroua at Old Kawa Wool Station at S23: 287 038									

*Upstream to downstream location

Groundwater

Groundwater resources in the Oroua Catchment are limited and in most area cannot be used as an alternative to surface water. There is little scope for using shallow groundwater resources in the catchment since the water is sometimes contaminated with iron and manganese making it unsuitable for uses such water supply. In Feilding area, high quality groundwater is found in aquifers at least 60 meters deep, but tapping aquifer at this depth is expensive. In some other areas of the catchment, there is no deep aquifer resource for development. The geology of the Oroua Catchment indicates that bores of a depth less than 20 meters which are also within 500 meters of the river channel are likely to be drawing from surface water resources. The portion of the catchment above Feilding enables surface water flow to enter the groundwater system. Using this groundwater, therefore, is likely to affect surface water flow. A policy treating groundwater abstractions that are hydraulically connected to the Oroua surface waters and which affect the flows of the associated river reaches in the same manner as surface water abstractions has been adopted.

Issues in the Catchment

Three significant water use-related issues have been identified in the Oroua Catchment. They include 1) adverse effects on river and stream environments caused by low flows in rivers during summer dry periods, 2) unacceptable water quality in the Oroua River downstream of Feilding at times of low flow, and 3) management of competing demands for surface water resources.

Oroua Catchment Water Allocation and River Flows Regional Plan

In an effort to continue addressing the conflict between the uses and protection of the river caused by water abstraction and waste discharge, the MWRC formulated the Oroua Catchment Water Allocation (OCWA) and River Flow Regional Plan that builds upon the Voluntary Water Management Agreement. The plan is aimed at the following objectives: 1) to maintain flows in rivers and streams of the catchment at a level that safeguards their life supporting capacity and minimizes any adverse effects on the environment; 2) to avoid, remedy or mitigate the adverse effects of low flows including unacceptable water quality; and 3) to achieve efficient and equitable use of surface water in the catchment.

The Plan has ten Regional Rules to manage surface water abstractions in the Oroua Catchment. These rules are set out in detail in Section 17 of the Plan. Of specific interest to this study are OCWA Rules 7, 8, and 9, which provide for the following:

a. Restriction of volumes and rates of maximum abstraction from the Oroua River and Kiwitea Stream
b. Suspension of the exercise of water permits for surface water abstraction for irrigation and reduction of those for public water supply.
c. Priority of use among user groups

The abstraction restrictions are triggered by a two-staged regime based on monthly flow thresholds at times of low river flows (Rule 7) and the suspensions defined by minimum flow levels for the Oroua River and Kiwitea Stream (Rules 8 and 9). Restrictions are apportioned to user groups, such as the Irrigators, the District Council (for public water supply), and to industry (Manawatu Beef Packers Ltd.). The flow restriction thresholds as they apply to different groups are shown in Table A-4. The rule on maximum rates of abstraction during low flows only applies to exercise of existing resource consents (those held as at 21 April 1994). New users, that is, those irrigators who did not hold permits as of 21 April 1994 are not allowed to take water from Oroua River or Kiwitea Stream when flows are at or below the specified thresholds, unless their water takes are in accordance with the rule on transferring water permit.

Rules 8 and 9 set the minimum flow thresholds of 915 lps for Oroua River at Almadale when the MDC abstraction for Feilding is sited upstream and 95 lps at Spur Road for the Kiwitea Stream, respectively. At or below these level, no user are allowed to abstract water except for the Manawatu District Council and Manawatu Beef Packers, though with provisions. The authorized amount for reduced MDC abstraction should not be greater than as follows: 1) 85 lps for the Feilding water supply; 2) 13 lps for the Kiwitea rural water supply; 3) 5 lps for the Oroua rural water supply; and 4) 5 lps for Waituna West rural water supply. On the other hand, the Manawatu Beef Packers may abstract water provided this abstraction is equalled or exceeded by their discharge of clean cooling water. However, the taking of up to 5 m^3 of water per day is a permitted activity and remains unaffected by minimum flow rules.

Table A-4. Flow Restriction Thresholds for Different Water Users (MWRC, 2000)

a. Limits on combined maximum abstraction (for the purpose of irrigation) from the Oroua River during times of low flow when the MDC water supply abstraction for Feilding is sited upstream of Almadale*

Maximum total abstraction for permits granted under OCWA Rules 4 or 5	Oroua River flow (lps at Almadale MWRC Recorder Site) at which abstraction restrictions take effect					
	Nov	Dec	Jan	Feb	Mar	Apr
50 lps	1015	1015	1015	1015	1015	1015
120 lps	1850	1800	1300	NA	1650	1800
Abstraction rate and time of day not restricted	> 1850	> 1800	> 1300	> 1015	> 1650	> 1800

* also subject to OCWA Rule 8

b. Limits on combined maximum abstraction (for the purpose of irrigation) from the Kiwitea Stream*

Maximum total abstraction for permits granted under OWCA Rules 3 or 5	Kiwitea Stream flow (lps at Spur Road Extension MWRC Recorder Site) at which abstraction restrictions take effect					
	Nov	Dec	Jan	Feb	Mar	Apr
20 lps	300	250	200	150	350	300
Abstraction rate and time of day not restricted	> 300	> 250	> 200	> 150	> 350	> 300

*subject to OCWA Rule 9

c. Restrictions during times of low flow to apply to the Manawatu District Council for abstractions for the Feilding Water Supply from Oroua River when the take is upstream of the MWRC flow recorder at Almadale.

Maximum abstraction by permits granted to Manawatu District Council	Oroua River flow (lps at Almadale MWRC Recorder Site) at which abstraction restrictions take effect					
	Nov	Dec	Jan	Feb	Mar	Apr
7000 m^3/day and < 85 lps	1015	1015	1015	1015	1015	1015
7000 m^3/day and < 100 lps	1850	1800	1300	NA	1650	1800
Up to 9000 m^3/day	> 1850	> 1800	> 1300	> 1015	> 1650	> 1800

d. Restrictions to be implemented by Manawatu Beef Packers on abstractions for surface water from the Oroua River when the MDC abstraction for Feilding is sited upstream of Almadale recording station.

Maximum abstraction by Manawatu Beef Packers	Oroua River flow (lps at Almadale MWRC Recorder Site) at which abstraction restrictions take effect					
	Nov	Dec	Jan	Feb	Mar	Apr
No net effect on flows	1015	1015	1015	1015	1015	1015
300 m^3/day and < 25 lps	1850	1800	1300	NA	1650	1800
Up to permit level	> 1850	> 1800	> 1300	> 1015	> 1650	> 1800

Appendix 3-3a. Types of WRAP-SIM Input Records (Wurbs, 2000)

Basic Input File (root.DAT)

T1, T2, T3	Titles or Headings	Required T1 is first record. Optional T1 and T2 follow
**	Comments	Comments may be inserted throughout after T1/T2/T3 records JC record
FO	File Options	Optional FD record is located just after or just before T1/T2/T3 records
JD	Job Control Data	Required JD record follows FD or T1/T2/T3 records
CO	Control Point Output	CO, RO, WO, GO records are optional and are inserted in any order following the JD record and preceding the UC records
RO	Reservoir Output	
WO	Water Rights Output	
GO	Groups of Water Rights to Output	
UC	Monthly Use Factors	Set of all pairs of UC records follow JD and precede RF records
RF	Return Flow Factors	Set of all pairs of optional RF records follow UC and precede CP records
CP	Control Point	All CP records are grouped together; at least one
CI	Constant Inflows	Set of all CI records in any order follows set of all CP records
IF	Instream Flow	IF and WR records are grouped in any order, with the set of WS/OR, SO, ML, TO, TS, and SD records immediately following corresponding WR or IF record. OR must follow WS. Otherwise, WS, SO, ML, TO, TS, and SD records may be in any order, but the set must immediately follow the pertinent WR or IF record.
WR	Water Right	
SO	Supplemental Options	
TO	Target Options	
TS	Target Series	
ML	Monthly Limits	
WS	Storage and Hydropower	
OR	Operating Rules for a Mutiple-Reservoir System	
SD	Storage-Diversion Relationship for a Type 4 Water Right	
SV	Storage Volume	Set of all SV-SA table grouped together in any order, with each SA immediately following corresponding SV
SA	Surface Area	
PV	Storage Volume	Set of all PV-PE table grouped together in any order, with each PE immediately following corresponding PV
PE	Surface Elevation	
TQ	Tailwater Discharge	Set of all TQ-TE tables grouped together in any order, with each TE immediately following corresponding TQ
TE	Tailwater Elevation	

MS	Monthly Varying Storage Capacity	Set of all MS records grouped together
DI IS/IP	Drought Index Reservoirs	Set of all DI/IS/IP records grouped together. Each DI record must be followed by an IS record followed by an IP record
EA/EF	Evaporation Allocation/Factors	Set of all EA/EF records grouped together
ED	End of Data	

Streamflow (root.INF) and Evaporation-Precipitation (root.EVA) Files – Standard Default Format

(Optionally, IN an EV records may follow ED record in root.DAT file)

IN	Inflows	IN records are grouped together by year. The set of IN recors for all control points for a particular year is followed by the set for the next year
EV	Evaporation	EV records are organized the same as IN records

Flow Distribution File (root.DIS)

FD	Flow Distribution	Each FC record follows the corresponding FD record
FC	Flow Distribution Coefficients	The set of all WP records follows the set of all FD/FC records
WP	Watershed Parameters	
ED	End of Data	

Flow Adjustment File (root.ADJ)

FA	Flow Adjustment	Set of all FA records

Appendix 3-3b. Sequential Order of WRAP-HYD Input Records (Wurbs, 2000)

Basic Input File (filename root1.DAT)

**	Comments	Comments may be inserted throughout
FO	File Options	FO record is preceded only by optional comment ** records
JC	Job Control Data	the JC record follows the FO record
CP	Control Point	All CP records are grouped together following the JC record
CI	Constant Inflows	Set of optional CI records follows set of all CP records
SV	Storage Volumes	Set of all SV-SA tables grouped together in any order with,
SA	Surface Area	each SA immediately following corresponding SV
EP	Evaporation-Precipitation Specifications	All EP records are grouped together
AS, FA, RS, SC, EQ		Set of streamflow adjustments records listed below.

Streamflow adjustment records (EQ, AS, FA, RS, SC) are placed at the end of either the: Basic Input File (filename root1.DAT) or Streamflow File (filename root1.INf)

AS	adjustment Specifications	An AS record precedes each set of FA records
FA	Flow Adjustments	and each set of RS/SC records. FA records for CP are grouped.
RS	Reservoir Specifications	A RS record precedes each group of SC records
SC	Storage Content	SC records for a control point are grouped together
EQ	Regression Equation	EQ records may be before, after, or between AS records
ED	End of Data	ED is last record in files containing AS/FA/RS/RC records.

Streamflow File (filename root1.INF)

**	Comments	Comments may be inserted before each group of records
IN	Inflows	IN records are grouped together by year and control point. Control points may be in any order. Years should be in sequential chronological order. IN record precede flow adjustment record sets

Evaporation-Precipitation Depth File (filename root1.EVA)

**	Comments	Comments may be inserted before each group of records
EV	Evaporation	EV records are organized the same as IN records

Flow Distribution File (filename root1.DIS)

**	Comments	Comments may be inserted before each group of records
FD	Flow Distribution	Each FC record follows the corresponding FD record. The set of all WP records follows the set of all FD/FC records.
FC	Flow Distribution Coefficients	
WP	Watershed Parameters	
ED	End of Data	

Hydrology File (filename root2.HYD) [alternative to standard INF and EVA files]

IN	Inflows	IN/EV records are grouped by year.
EV	Evaporation	Set of EV records for all control points for year follow set of all IN records for the preceding year.

Appendix 3-3c. Program TABLES Input Records and Associated Tables (Wurbs, 2000)

Miscellaneous Records

TITL	Titles or headings
COMM	comments
ENDF	end of input data file

Job Type 1 Records – Develop Tables from WRAP-SIM Input File

1REC	listing of specified input records
1SUM	water rights summary by control point or type of use
1SRT	listing of water rights sorted by priority, type of use, control point, or water right type

Job Type 2 Records – Develop Tables from WRAP-SIM Output File

2SCP	summary table for a control point
2SWR	summary table for a water right
2SRE	summary table for a reservoir
2SGP	summary table for a water right group
2SBA	summary table for a river basin (all control points)
2NAT	naturalized streamflows
2REG	regulated streamflows
2UNA	unappropriated streamflows
2DEP	streamflow depletions
2DIV	diversions
2SHT	diversion shortages
2IFS	instream flow shortages
2CLO	channel losses
2CLC	channel loss credits
2STO	reservoir storages
2PER	percentage of storage capacity and storage-duration for selected reservoirs
2REL	reliability and shortage summary
2FRE	frequency statistics for streamflow, storage, or instream flow shortage
2FRQ	frequencies for specified streamflow, storage, or instream flow shortage

Job Type 3 Records – Develop Streamflow Records from WRAP-SIM Output File

3REG	records of regulated streamflows
3NAT	records of naturalized streamflows
3UNA	records of unappropriated streamflows
3DEP	records of streamflow depletions
3U+D	records of unappropriated flows plus streamflow depletions

Job Type 4 Record – Develop Tables from WRAP-SIM System Release/Hydropower File

4SWR	system reservoir releases for selected water rights
4SGP	system reservoir releases for selected water right groups

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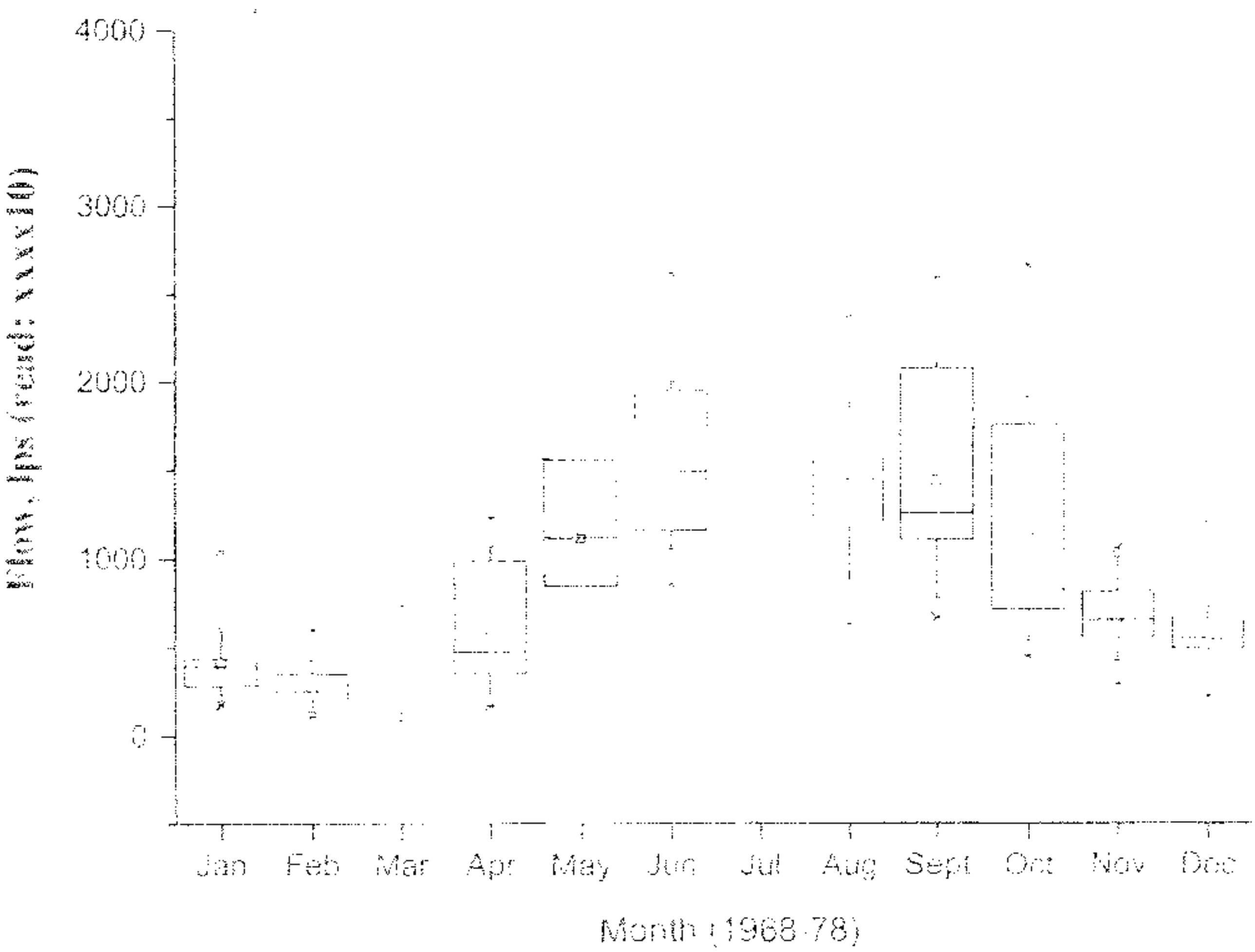
Appendix 3-4a. Box Plot of Oroua River Flow at Almadale



Appendix 3-4b. Mann-Kendall Test for Trend

Ho: no trend
Ha: presence of trend
Decision: p-value > a-value: accept Ho
p-value < a-value; reject Ho (meaning, presence of trend)

For the Oroua River at Almadale (1948-78)

Month	S*	p value at n = 31	α 0.05	α 0.1
Jan	-60	-0.16	accept	accept
Feb	-111	0.03	reject	reject
Mar	-84	-0.08	accept	reject
Apr	-151	0.01	reject	reject
May	-139	0.01	reject	reject
Jun	-137	0.01	reject	reject
Jul	-71	0.12	accept	accept
Aug	-133	0.01	reject	reject
Sep	-14	-0.41	accept	accept
Oct	-83	0.08	accept	reject
Nov	-103	0.04	reject	reject
Dec	-84	0.08	accept	reject

* Mann Kendall statistic

For the Kiwitea Stream at Spur Rd. (1977-1997)

Month	S*	p-value at n = 21	α 0.05	α 0.1
Jan	26	0.23	accept	accept
Feb	93	0.00	reject	reject
Mar	72	0.02	reject	reject
Apr	51	0.07	accept	reject
May	40	0.12	accept	accept
Jun	72	0.02	reject	reject
Jul	32	0.18	accept	accept
Aug	18	0.31	accept	accept
Sep	2	0.49	accept	accept
Oct	50	0.07	accept	reject
Nov	55	0.05	accept	reject
Dec	7	0.43	accept	accept

Median: Seasonal Kendall Slope Estimate l/s/yr

(Read xxxx0)

	Almadale	Spur Rd
Jan	-51	8
Feb	-93	15
Mar	-67	15
Apr	-220	40
May	-336	35
Jun	-240	85.5
Jul	-262	51
Aug	-384	10.5
Sep	-34	10.5
Oct	-179	94.5
Nov	-169	30
Dec	-134	3.5

(-) value indicates downward trend

Formulas:

$$S_i = \sum_{k=1}^{n_i-1} \sum_{l=k+1}^{n_i} \mathrm{sgn}(x_{il} - x_{ik})$$

$$Q_i = \frac{x_{il} - x_{ik}}{l - k}$$

where: Si = Kendall statistic for season i
ni = the no. of data over years for season i
k = no. of season
l = no. of year
sgn (xil - xik) = 1 if $x_{il} - x_{ik} > 0$
= 0 if $x_{il} - x_{ik} = 0$
= -1 if $x_{il} - x_{ik} < 0$

Qi = individual slope estimate for ith season
Seasonal Kendall slope estimator = median of individual slope estimates

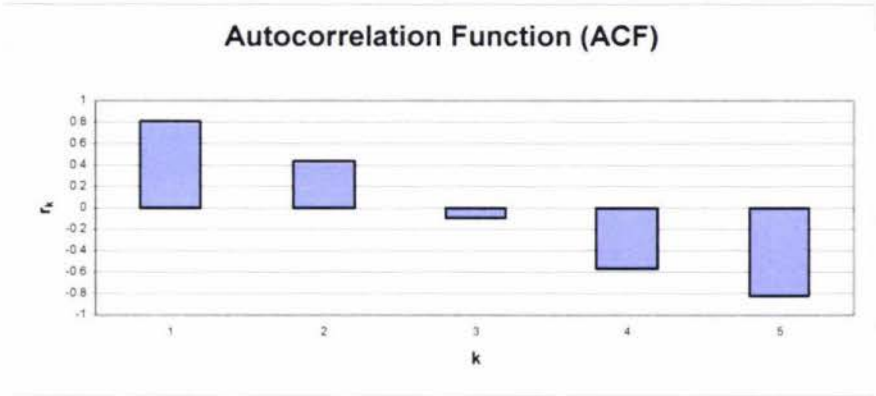
Appendix 3-4c. Autocorrelation and Partial Autocorrelation Values of the Mean Monthly Flow Series (1948-78) for Oroua River at Almadale

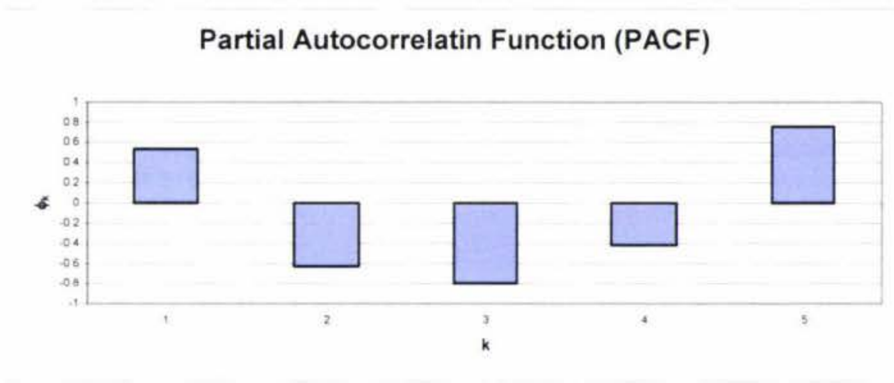
Covariance Values, C(k)		lag, k				
	mean	1	2	3	4	5
Dec	827.6					
Jan	611.4	161151.7				
Feb	475.8	345470.7	202858.4			
mar	549.4	386335.6	306906.9	180213.9		
Apr	740.3	231390.0	260464.9	206914.6	121499.1	
May	1348.9	-84395.2	-125179.5	-140908.7	-111938.6	-65729.7
Jun	1771.1	135855.2	-251123.7	-372480.2	-419283.5	-333080.8
Jul	1959.1	523777.5	176026.0	-325378.1	-482618.3	-543260.9
Aug	1820.1	564170.5	435421.3	146332.2	-270490.0	-401205.3
Sep	1413.9	190802.3	229520.1	177141.4	59532.0	-110042.8
Oct	1200.4	18144.9	44600.9	53651.3	41407.6	13915.9
Nov	905.2	-14985.5	-64108.1	-157580.4	-189556.8	-146298.1
mean	1135.3	223428.9	121538.7	-25788.2	-156431.1	-226528.8
variance	275957.3					
stdev	525.3					
autocorrelation	0.0041	0.8097	0.4404	-0.0935	-0.5669	-0.8209

k	auto	partial
0	1	1
1	0.8097	0.5348
2	0.4404	-0.6245
3	-0.0935	-0.7953
4	-0.5669	-0.4159
5	-0.8209	0.7592

ϕj(k)		j	
k	1	2	3
1	0.8097		
2	1.3152		
3	0.8186	0.4215	
4	0.4879	0.5968	-0.4549
5	0.8036		

Appendix 3-4d. Autocorrelation and Partial Autocorrelation Functions of the Mean Monthly Flow Series (1948-78) for Oroua River at Almadale





Formulas:
covariance at lag k, C(k):

$$C_k = \frac{1}{N}\sum_{t=1}^{n-k}(Y_t - \overline{Y})(Y_{t+k}) - \overline{Y})$$ where Y is the observed data
$\overline{Y}$ is the mean of the series

Autocorrelation Function, rk:

$$r_k = \frac{C_k}{C_0}$$

Partial Autocorrelation Function, fk(k):

$$\phi_k(k) = \frac{r_k - \sum_{j=1}^{k-1}\phi_j(k-1)r_{k-j}}{1 - \sum_{j=1}^{k-1}\phi_j(k-1)r_j}$$

$$\phi_j(k) = \phi_j(k-1) - \phi_k(k)\phi_{k-j}(k-1)$$

Appendix 3-5. Flow Adjustment (FA) Estimates for the Gauged Control Points (CP)*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CP3												
1993	0.0	0.0	0.0	0.0	0.0	0.0	9.0	18.5	68.3	68.8	74.1	75.2
1994	50.2	80.4	73.8	65.6	67.5	60.2	68.6	68.3	68.3	68.8	74.1	75.2
1995	50.2	80.4	73.8	65.6	67.5	60.2	139.4	241.6	241.6	243.2	276.1	280.4
1996	187.0	308.2	270.5	240.4	234.5	209.1	238.4	237.5	237.4	239.1	271.6	275.9
1997	184.0	294.7	270.5	227.8	234.5	209.1	238.4	237.5	237.4	239.1	271.6	275.9
1998	184.0	294.7	270.5	227.8	234.5	209.1	238.4	237.5	237.4	239.1	271.6	275.9
CP12												
1993	17.0	27.2	25.0	14.2	14.6	13.0	14.9	14.8	14.8	14.9	25.1	25.4
1994	17.0	27.2	25.0	14.2	14.6	13.0	14.9	14.8	14.8	14.9	25.1	25.4
1995	17.0	27.2	25.0	14.2	14.6	13.0	14.5	14.5	14.5	14.6	24.7	26.0
1996	17.3	76.5	79.5	13.9	14.3	12.7	14.5	14.5	14.5	14.6	69.9	71.0
1997	54.1	86.6	79.5	13.9	14.3	12.7	14.5	14.5	14.5	14.6	79.8	81.1
1998	54.1	86.6	79.5	13.9	14.3	12.7	14.5	14.5	14.5	14.6	79.8	81.1
CP17												
1993	99.4	159.2	146.1	125.1	128.7	114.8	130.9	130.4	130.3	130.9	173.9	176.7
1994	117.8	188.7	173.2	124.8	128.3	113.9	129.9	129.4	129.3	130.2	173.2	175.9
1995	117.3	187.8	172.3	124.0	127.6	113.8	129.7	129.2	129.2	130.1	173.0	180.0
1996	165.4	385.2	360.8	124.0	127.6	-55.7	-102.2	-101.8	-101.7	-102.5	111.9	113.7
1997	75.8	121.5	111.5	-97.6	-100.5	-89.6	-102.2	-101.8	-101.7	-102.5	111.9	113.7
1998	75.8	121.5	111.5	-97.6	-100.5	-89.6	-102.2	-101.8	-101.7	-102.5	111.9	113.7

* unit in acre-ft/month

Assumptions in Flow Adjustments computations:

a. All consent holders abstract/discharge the same percentage of their permitted volume as the MDC/Feilding Water Supply (WR-100790)

b. Water abstraction for irrigation purposes only occurs from November to March every year.

Formulas:

$$UC = \frac{Actual\ diversion}{Permitted\ diversion\ volume} \qquad FA = \sum (diversion\,vol.* no.\,of\ days) - (discharge\ vol.* no.\,of\ days)$$

where diversion and discharge volumes are in lps

Appendix 3-6a. WRAP-HYD Model for Naturalized Flow Determination (Basic Data)

```
**      WRAP-HYD Input File for Oroua River Catchment
**      Naturalized flow determination for the Oroua River   hydi2 dat
FO           1              1                       1       1
JC           6     1993     1       2               1                   3
**      Control point representation of water rights, takes, discharges, and instream flow requirements
**      Drainage area ration
CP      CP1     CP2                     5
CP      CP2     CP3                     5
CP      CP3     CP4                     1
CP      CP4     CP5                     5
CP      CP5     CP6                     5
CP      CP6     CP7                     5
CP      CP7     CP15                    5
CP      CP8     CP9                     5
CP      CP9     CP10                    5
CP      CP10    CP11                    5
CP      CP11    CP12                    5
CP      CP12    CP14                    1
CP      CP14    CP15                    5
CP      CP15    CP16                    5
CP      CP16    CP17                    5
CP      CP17    OUT                     5
**      Streamflow adjustment s (AS/FA) record at CP3 (abstraction less discharges)
AS      CP3        1993     1998      -1       1
FA      CP3        1993        0       0       0       0       0       0       9    18.5    68.3    68.8    74.1    75.2
FA      CP3        1994     50.2    80.4    73.8    65.6    67.5    60.2    68.6    68.3    68.3    68.8    74.1    75.2
FA      CP3        1995     50.2    80.4    73.8    65.6    67.5    60.2   139.4   241.6   241.6   243.2   276.1   280.4
FA      CP3        1996      187   308.2   270.5   240.4   234.5   209.1   238.4   237.5   237.4   239.1   271.6   275.9
FA      CP3        1997      184   294.7   270.5   227.6   234.5   209.1   238.4   237.5   237.4   239.1   271.6   275.9
FA      CP3        1998      184   294.7   270.5   227.8   234.5   209.1   238.4   237.5   237.4   239.1   271.6   275.9
**      Streamflow adjustment s (AS/FA) record at CP12 (abstraction less discharges)
AS      CP12       1993     1998      -1       1
FA      CP12       1993       17    27.2      25    14.2    14.6      13    14.9    14.8    14.8    14.9    25.1    25.4
FA      CP12       1994       17    27.2      25    14.2    14.6      13    14.9    14.8    14.8    14.9    25.1    25.4
FA      CP12       1995       17    27.2      25    14.2    14.6      13    14.5    14.5    14.5    14.6    24.7      26
FA      CP12       1996     17.3    76.5    79.5    13.9    14.3    12.7    14.5    14.5    14.5    14.6    69.9      71
FA      CP12       1997     54.1    86.6    79.5    13.9    14.3    12.7    14.5    14.5    14.5    14.6    79.8    81.1
FA      CP12       1998     54.1    86.6    79.5    13.9    14.3    12.7    14.5    14.5    14.5    14.6    79.8    81.1
**      Streamflow adjustments (AS/FA) records at CP 17 (abstraction less discharges)
AS      CP17       1993     1998      -1       1
FA      CP17       1993     99.4   159.2   146.1   125.1   128.7   114.8   130.9   130.4   130.3   130.9   173.9   176.7
FA      CP17       1994    117.8   188.7   173.2   124.8   128.3   113.9   129.9   129.4   129.3   130.2   173.2   175.9
FA      CP17       1995    117.3   187.8   172.3     124   127.6   113.8   129.7   129.2   129.2   130.1     173     180
FA      CP17       1996    165.4   385.2   360.8     124   127.6   -55.7  -102.2  -101.8  -101.7  -102.5   111.9   113.7
FA      CP17       1997     75.8   121.5   111.5   -97.6  -100.5   -89.6  -102.2  -101.8  -101.7   102.5   111.9   113.7
FA      CP17       1998     75.8   121.5   111.5   -97.6  -100.5   -89.6  -102.2  -101.8  -101.7   102.5   111.9   113.7
**      End of HYD DAT File Record
ED
```

Appendix 3-6b. WRAP-HYD Model for Naturalized Flow Determination (Inflow File)

**	Oroua WRAP-HYD Input File: hydi2.inf													
**	Naturalized streamflows at gauged control points (IN records); IN values for CP17 are predicted and not used in WRAP-HYD flow distribution													
IN	CP3	1993	12681	15886.3	9228.5	12419	20324.4	24859.1	11638.7	13831.9	23009.9	14591.8	16558.7	10401
IN	CP3	1994	6166.8	3471.4	6839.9	7291.7	35611.1	27611.9	42688.1	25557.4	31163.2	27663.7	31142.2	8012.5
IN	CP3	1995	6731.4	7511.7	6514.2	15276.9	18326.7	27822	42776.7	23885.5	34567.4	30834	19878.9	8034.2
IN	CP3	1996	11508.5	11355.1	10335.9	26918.4	24146	27107.5	27034	28662.6	16222.5	22300.3	16558.7	13723.3
IN	CP3	1997	10487.9	3863.7	16394.1	20845.5	8294.8	22904.8	33765.4	22604.3	20131	36001.9	15865.3	12051.3
IN	CP3	1998	3886.8	5530.8	3713.1	9939.4	15113	19857.9	42038.4	18066.1	17000	27186	15802.2	11769
IN	CP12	1993	3865.1	1117.9	1454.8	2122.4	3734.8	6955.5	2974.8	3105.1	7627.9	2432	5106.3	2453.7
IN	CP12	1994	1498.3	666.8	1042.3	1407.9	5732.5	10254.6	14570.1	14135.9	12419	8511.9	11263.3	1541.7
IN	CP12	1995	846.8	961	1064	2941.9	3756.5	9918.4	18478.7	9293.6	10990.1	13462.7	5085.3	2540.5
IN	CP12	1996	1411.4	1686.7	2301.7	5106.3	11486.7	9414.1	12377	12029.6	6430.2	7404.5	2962.9	2627.4
IN	CP12	1997	1628.6	706.1	2280	6556.2	2019.4	6724.4	4885.7	7665.1	5400.5	12333.6	2437.6	1824
IN	CP12	1998	539.7	983.1	497	2038.2	3294.3	4590.1	10053.6	4171.4	3918.2	6409.2	3624.3	2626.2
IN	CP17	1993	18137.3	22347.8	13490.4	17750.2	28424.6	34493.5	16734.4	15851.6	28293.8	16874.5	19611	11234
IN	CP17	1994	9369.6	5638.4	10275.6	10849.2	48999.4	38198.6	58497.6	31633.4	39267.5	34468.2	39239.2	8019.2
IN	CP17	1995	10129.5	11076.2	9837.2	21596.6	25735.9	38481.4	58643.8	29383	43849.3	38735.2	24079.6	8048.4
IN	CP17	1996	16559.1	16283.6	14980.9	37265.2	33568.3	37519.8	37455.3	35812.6	19158.4	27249.6	19611	15705.5
IN	CP17	1997	15185.5	6166.3	23134.8	29091.5	12233.7	31863.2	46515.2	27658.7	24419	45690.8	18677.6	13455.1
IN	CP17	1998	6300.9	8410.1	6067.1	14412.8	21410.5	27762.2	57650.1	21550.6	20204.9	33825.3	18592.8	13075.2
**	End of Input Records													
ED														

Appendix 3-6c. WRAP-HYD Model for Naturalized Flow Determination (Distribution File)

```
**      WRAP-HYD Files for Oroua River Management
**      Oroua WRAP-HYD Flow Distribution File: hydi2.dis
**      (-1) indicating ungauged CP is downstream of gauged CP
FD      CP1     CP3
FD      CP2     CP3
FD      CP4     CP3             -1
FD      CP5     CP3             -1
FD      CP6     CP3             -1
FD      CP7     CP3             -1
FD      CP8     CP12
FD      CP9     CP12
FD      CP10    CP12
FD      CP11    CP12
FD      CP14    CP12            -1
FD      CP15    CP3             -1
FD      CP16    CP3             -1
FD      CP17    CP3             -1
**      Watershed Parameter (WP) records
**      Total drainage area (ha) is used; 0.003861 conversion factor to sq mile
WP      CP1      22671.8        0.003861
WP      CP2     28878.07        0.003861
WP      CP3     30439.96        0.003861
WP      CP4      31240.2        0.003861
WP      CP5     31263.02        0.003861
WP      CP6     31798.01        0.003861
WP      CP7     31992.01        0.003861
WP      CP8      2909.89        0.003861
WP      CP9     14953.69        0.003861
WP      CP10    16036.89        0.003861
WP      CP11    23517.77        0.003861
WP      CP12    23860.75        0.003861
WP      CP14    24443.16        0.003861
WP      CP15    56898.05        0.003861
WP      CP16    57100.06        0.003861
WP      CP17    57180.51        0.003861
**      End of WP records
ED
```

Appendix 3-7a. WRAP Model for Oroua Water Allocation Based on Full Permitted Rates (Basic Data File)

```
T1      WRAP-SIM Input File for Oroua Water Allocation Management Based on Full Permitted Abstraction Rates
T2      Oroua WRAP-SIM Input File:  simi2.dat
**      Using natural upstream-to-downstream priority allocation
FO                      -1
JD              6     1993        1        -1        -1                                  0
**      Control Point (CP) records
CP      CP1      CP2                                 7    NONE
CP      CP2      CP3                                 7    NONE
CP      CP3      CP4                                 1    NONE
CP      CP4      CP5                                 7    NONE
CP      CP5      CP6                                 7    NONE
CP      CP6      CP7                                 7    NONE
CP      CP7      CP15                                7    NONE
CP      CP8      CP9                                 7    NONE
CP      CP9      CP10                                7    NONE
CP      CP10     CP11                                7    NONE
CP      CP11     CP12                                7    NONE
CP      CP12     CP14                                1    NONE
CP      CP14     CP15                                7    NONE
CP      CP15     CP16                                7    NONE
CP      CP16     CP17                                7    NONE
CP      CP17     OUT                                 7    NONE
**      Water Right (WR) and Instream Flow (IF) records
**      Using type 0 IF computation (i.e., IF shortages determine only)
WR      CP1            767          1                                 WR-MWC912876
WR      CP2           2663          1                                 WR-100790
WR      CP3            202          1                                 WR-4514
IF      CP3          23393          1        0              IF3
WR      CP3            284          1                                 WR-3600
IF      CP4          23393          1        0              IF4
WR      CP4            391          1                                 WR-3675
IF      CP5          23393          1        0              IF5
WR      CP5           2071          1                                 WR-4586
IF      CP6          23393          1        0              IF6
WR      CP6            178          1                                 WR-4487
WR      CP6            362          1                                 WR-4447
IF      CP7          23393          1        0              IF7
WR      CP7             77          1                                 WR-MWT820019
WR      CP8             12          1                                 WR-6092
WR      CP9            227          1                                 WR-MWC912875
WR      CP10           128          1                                 WR-MWT701526
WR      CP11           769          1                                 WR-6273
IF      CP12          2429          2        0              IF12
IF      CP14          2429          2        0              IF14
WR      CP14             9          1                                 WR-4796
IF      CP15         23393          1        0              IF15
WR      CP15            67          1                                 WR-6105
IF      CP16         23393          1        0              IF16
WR      CP16          2018          1                                 WR-MWT690185
IF      CP17         23393          1        0              IF17
**      End of Records
ED
```

Appendix 3-7b. WRAP Model for Oroua Water Allocation Based on Full Permitted Rates (Distribution File)

```
**      WRAP-HYD File for Oroua River Management
**      Oroua      WRAP-HYD Flow Distribution File:  simi2.dis
**      (-1) indicating ungauged CP is downstream of gauged CP
FD      CP1        CP3
FD      CP2        CP3
FD      CP4        CP3               -1
FD      CP5        CP3               -1
FD      CP6        CP3               -1
FD      CP7        CP3               -1
FD      CP8        CP12
FD      CP9        CP12
FD      CP10       CP12
FD      CP11       CP12
FD      CP12       CP12
FD      CP14       CP12              -1
FD      CP15       CP3               -1
FD      CP16       CP3               -1
FD      CP17       CP3               -1
**      Watershed Parameter (WP) records
**      Total drainage area (ha) is used; 0.003861 conversion factor to sq.mile
WP      CP1          22671.8         0.003861
WP      CP2         28878.07         0.003861
WP      CP3         30439.36         0.003861
WP      CP4          31240.2         0.003861
WP      CP5         31263.02         0.003861
WP      CP6         31798.01         0.003861
WP      CP7         31992.01         0.003861
WP      CP8          2909.89         0.003861
WP      CP9         14953.69         0.003861
WP      CP10        16036.89         0.003861
WP      CP11        23517.77         0.003861
WP      CP12        23860.75         0.003861
WP      CP14        24443.16         0.003861
WP      CP15        56898.05         0.003861
WP      CP16        57100.06         0.003861
WP      CP17        57180.51         0.003861
**      End of WP records
ED
```

Appendix 3-7c. WRAP Model for Oroua Water Allocation Based on Full Permitted Rates (Inflow File)

** WRAP-SIM Input File for Oroua River Water Allocation Management Based on Permitted Rates

** WRAP-SIM Input File: simi2.inf

** Naturalized Flow at CPs

IN	CP3	1993	12681	15886.3	9228.5	12419	20324.4	24859.1	11647.7	13850.3	23078.2	14660.6	16632.8	10476.3
IN	CP12	1993	3882.1	1145.1	1479.8	2136.6	3749.4	6968.5	2989.7	3119.9	7642.7	2446.9	5131.4	2479.1
IN	CP3	1994	6217.2	3551.8	6913.7	7357.3	35678.5	27672	42736.7	25625.8	31231.5	27732.5	31216.2	8087.7
IN	CP12	1994	1515.2	694	1067.2	1422.1	5747.1	10267.7	14585	14150.7	12433.8	8526.8	11288.3	1567.1
IN	CP3	1995	6781.5	7592	6588	15342.5	18394.2	27882.2	42916.1	24127.1	34808.9	31077.2	20155	8314.6
IN	CP12	1995	863.8	988.2	1088.9	2956.1	3771.1	9931.5	18493.2	9308.1	11004.6	13477.3	5110	2566.5
IN	CP3	1996	11695.5	11663.3	10606.4	27158.9	24380.5	27316.6	27272.4	28900	16459.9	22539.4	16830.3	13999.2
IN	CP12	1996	1428.7	1763.2	2381.2	5120.2	11501	9426.8	12391.5	12044.1	6444.6	7419.1	3032.9	2698.4
IN	CP3	1997	10671.9	4158.4	16664.6	21073.3	8529.3	23113.9	34003.8	22841.8	20368.4	36241	16136.9	12327.2
IN	CP12	1997	1682.6	792.7	2359.5	6570.1	2033.7	6637.1	4900.2	7679.5	5415	12348.1	2517.4	1905.1
IN	CP3	1998	4070.8	5825.5	3983.6	10167.3	15347.5	20066.9	42276.8	18303.6	17237.4	27425.1	16073.9	12044.9
IN	CP12	1998	593.7	1069.8	576.5	2052.1	3308.6	4602.8	10068.1	4185.8	3932.7	6423.7	3704.1	2707.3

Appendix 3-8. WRAP Model for Oroua Water Allocation Based on Estimated Abstraction Rates (Basic Data File)

```
T1    WRAP-SIM Input File for Oroua Water Allocation Management Based on Estimated Abstraction Rates
T2    Oroua WRAP-SIM Input File:  simi2e2.dat
**    Using natural upstream-to-downstream priority allocation
FO            -1
JD          6    1993       1      -1      -1                                     0
**    Use coefficient (UC) record for different water use types to distribute the annual permitted abstraction among months
**    UC identifiers:  muni1=MWC912876; muni2=WR100790; muni3=WR3600; muni9=MWC912875; irrig=all rights for the
**    purpose of irrigation; & indus=WR-MWT690185
UC    muni1    0.56223  0.99718  0.82668  0.75929  0.75629  0.69674          YES
UC             0.76895  0.76585  0.79115  0.77094  0.85773  0.84304           0.783006
UC    muni2    0.56223  0.99718  0.82668  0.75929  0.75629  0.69674          YES
UC             0.76895  0.76585  0.79115  0.77094  0.85773  0.84304           0.783006
UC    muni3    0.56223  0.99718  0.82668  0.75929  0.75629  0.69674          YES
UC             0.76895  0.76585  0.79115  0.77094  0.85773  0.84304           0.783006
UC    muni9    0.56223  0.99718  0.82668  0.75929  0.75629  0.69674          YES
UC             0.76895  0.76585  0.79115  0.77094  0.85773  0.84304           0.783006
UC    irrig    0.56223  0.99718  0.82668  0.75929  0.75629  0.69674          YES
UC             0.76895  0.76585  0.79115  0.77094  0.85773  0.84304           0.783006
UC    indus    0.56223  0.99718  0.82668  0.75929  0.75629  0.69674          YES
UC             0.76895  0.76585  0.79115  0.77094  0.85773  0.84304           0.783006
**    Control Point (CP) records
CP    CP1      CP2                             7 NONE
CP    CP2      CP3                             7 NONE
CP    CP3      CP4                             1 NONE
CP    CP4      CP5                             7 NONE
CP    CP5      CP6                             7 NONE
CP    CP6      CP7                             7 NONE
CP    CP7      CP15                            7 NONE
CP    CP8      CP9                             7 NONE
CP    CP9      CP10                            7 NONE
CP    CP10     CP11                            7 NONE
CP    CP11     CP12                            7 NONE
CP    CP12     CP14                            1 NONE
CP    CP14     CP15                            7 NONE
CP    CP15     CP16                            7 NONE
CP    CP16     CP17                            7 NONE
CP    CP17     OUT                             7 NONE
**    Water    Right (   WR) and  Instream  Flow (I   F) recor   ds
**    Using type 0 IF computation (i.e., IF shortages determined only)
WR    CP1          767    muni1       1                                 WR-MWC912876
WR    CP2         2663    muni2       1                                 WR-100790
WR    CP3          202    irrig       1                                 WR-4514
IF    CP3        23393                1       0               IF3
WR    CP3          284    muni3       1                                 WR-3600
IF    CP4        23393                1       0               IF4
WR    CP4          391    irrig       1                                 WR-3675
IF    CP5        23393                1       0               IF5
WR    CP5         2071    irrig       1                                 WR-4586
IF    CP6        23393                1       0               IF6
WR    CP6          178    irrig       1                                 WR-4487
WR    CP6          362    irrig       1                                 WR-4447
IF    CP7        23393                1       0               IF7
WR    CP7           77    irrig       1                                 WR-MWT820019
WR    CP8           12    irrig       1                                 WR-6092
WR    CP9          227    muni9       1                                 WR-MWC912875
WR    CP10         128    irrig       1                                 WR-MWT701526
WR    CP11         769    irrig       1                                 WR-6273
IF    CP12        2429                2       0               IF12
IF    CP14        2429                2       0               IF14
WR    CP14           9    irrig       1                                 WR-4796
IF    CP15       23393                1       0               IF15
WR    CP15          67    irrig       1                                 WR-6105
IF    CP16       23393                1       0               IF16
WR    CP16        2018    indus       1                                 WR-MWT690185
IF    CP17       23393                1       0               IF17
**    End of Records
ED
```

Appendix 3-9. WRAP Model for Alternative Allocation Scheme Based on the Combined Maximum Abstraction Rates

T1	WRAP-SIM Input File for Irrigation-related Rights using ***Proportional Allocation***							
T2	Oroua WRAP-SIM Input File: simi2pr.dat							
**								
FO		-1						
JD	6	1993	1	-1	-1			0
**	Control Point (CP) records							
CP	CP1	CP2			7	NONE		
CP	CP2	CP3			7	NONE		
CP	CP3	CP4			1	NONE		
CP	CP4	CP5			7	NONE		
CP	CP5	CP6			7	NONE		
CP	CP6	CP7			7	NONE		
CP	CP7	CP15			7	NONE		
CP	CP8	CP9			7	NONE		
CP	CP9	CP10			7	NONE		
CP	CP10	CP11			7	NONE		
CP	CP11	CP12			7	NONE		
CP	CP12	CP14			1	NONE		
CP	CP14	CP15			7	NONE		
CP	CP15	CP16			7	NONE		
CP	CP16	CP17			7	NONE		
CP	CP17	OUT			7	NONE		
**	Water Right (WR) and Instream Flow (IF) records							
**	Using type 0 IF computation (i.e., IF shortages determined only)							
**	Proportional allocation of the remaining flow under the combined maximum abstraction rule among							
**	irrigation rights held after 21 April 1994							
WR	CP1	767		1			WR-MWC912876	
WR	CP2	2663		1			WR-100790	
WR	CP3	57		2			WR-4514	
IF	CP3	23393		1	0	IF3		
WR	CP3	284		1			WR-3600	
IF	CP4	23393		1	0	IF4		
WR	CP4	391		1			WR-3675	
IF	CP5	23393		1	0	IF5		
WR	CP5	583		2			WR-4586	
IF	CP6	23393		1	0	IF6		
WR	CP6	50		2			WR-4487	
WR	CP6	102		2			WR-4447	
IF	CP7	23393		1	0	IF7		
WR	CP7	77		1			WR-MWT820019	
WR	CP8	6		2			WR-6092	
WR	CP9	227		1			WR-MWC912875	
WR	CP10	128		1			WR-MWT701526	
WR	CP11	373		2			WR-6273	
IF	CP12	2429		2	0	IF12		
IF	CP14	2429		2	0	IF14		
WR	CP14	4		2			WR-4796	
IF	CP15	23393		1	0	IF15		
WR	CP15	19		2			WR-6105	
IF	CP16	23393		1	0	IF16		
WR	CP16	2018		1			WR-MWT690185	
IF	CP17	23393		1	0	IF17		
**	End of Records							
ED								

Appendix 3-10. WRAP Model for Alternative Allocation Scheme Based on the Combined Maximum Abstraction Rates

```
T1      WRAP-SIM Input File for Irrigation-related Rights using Ranked Priority Allocation
T2      Oroua WRAP-SIM Input File: simirk.dat
**
FO                      -1
JD             6      1993       1        -1        -1                     0
**      Control Point (CP) records
CP      CP1     CP2                                  7     NONE
CP      CP2     CP3                                  7     NONE
CP      CP3     CP4                                  1     NONE
CP      CP4     CP5                                  7     NONE
CP      CP5     CP6                                  7     NONE
CP      CP6     CP7                                  7     NONE
CP      CP7     CP15                                 7     NONE
CP      CP8     CP9                                  7     NONE
CP      CP9     CP10                                 7     NONE
CP      CP10    CP11                                 7     NONE
CP      CP11    CP12                                 7     NONE
CP      CP12    CP14                                 1     NONE
CP      CP14    CP15                                 7     NONE
CP      CP15    CP16                                 7     NONE
CP      CP16    CP17                                 7     NONE
CP      CP17    OUT                                  7     NONE
**      Water Right (WR) and Instream Flow (IF) records)
**      Using type 0 IF computation (i.e., IF shortages determined only)
**      Ranked priority allocation based on weighted criteria (prior use and upstream-to-downstream allocation)
WR      CP1             767           1                             WR-MWC912876
WR      CP2            2663           1                             WR-100790
WR      CP3             202           4                             WR-4514
IF      CP3           23393           1         0          IF3
WR      CP3             284           1                             WR-3600
IF      CP4           23393           1         0          IF4
WR      CP4             391           2                             WR-3675
IF      CP5           23393           1         0          IF5
WR      CP5             609           5                             WR-4586
IF      CP6           23393           1         0          IF6
WR      CP6               0           7                             WR-4487
WR      CP6               0           8                             WR-4447
IF      CP7           23393           1         0          IF7
WR      CP7              77           3                             WR-MWT820019
WR      CP8              12           3                             WR-6092
WR      CP9             227           1                             WR-MWC912875
WR      CP10            128           2                             WR-MWT701526
WR      CP11            362           5                             WR-6273
IF      CP12           2429           2         0          IF12
IF      CP14           2429           2         0          IF14
WR      CP14              9           4                             WR-4796
IF      CP15          23393           1         0          IF15
WR      CP15              0           6                             WR-6105
IF      CP16          23393           1         0          IF16
WR      CP16           2018           1                             WR-MWT690185
IF      CP17          23393           1         0          IF17
**      End of Records
ED
```

Appendix 4-1. Naturalized Streamflows (NAT in acre-ft/mo) Developed with WRAP

Year	Month	NAT CP1	NAT CP2	NAT CP3	NAT CP4	NAT CP5	NAT CP6	NAT CP7	NAT CP8	NAT CP9	NAT CP10	NAT CP11	NAT CP12	NAT CP14	NAT CP15	NAT CP16	NAT CP17
1993	1	9445	12030.6	12681	13014.6	13024.1	13247	13327.8	473.4	2432.9	2609.2	3826.3	3882.1	3976.9	23703.7	23787.8	23821.3
1993	2	11832.4	15071.5	15886.3	16304.3	16316.2	16595.4	16696.6	139.6	717.6	769.6	1128.6	1145.1	1173.1	29695.1	29800.5	29842.5
1993	3	6873.6	8755.2	9228.5	9471.3	9478.2	9640.4	9699.2	180.5	927.4	994.6	1458.5	1479.8	1515.9	17250.2	17311.4	17335.8
1993	4	9249.9	11782	12419	12745.7	12755	12973.3	13052.5	260.6	1339	1436	2105.9	2136.6	2188.8	23213.9	23296.3	23329.2
1993	5	15138	19281.9	20324.4	20859.1	20874.4	21231.6	21361.1	457.3	2349.8	2520	3695.5	3749.4	3840.9	37990.9	38125.8	38179.5
1993	6	18515.5	23584	24859.1	25513.1	25531.8	25968.7	26127.1	849.8	4367.2	4683.6	6868.3	6968.5	7138.6	46467.3	46632.3	46698
1993	7	8675.4	11050.3	11647.7	11954.1	11962.9	12167.6	12241.8	364.6	1873.7	2009.4	2946.7	2989.7	3062.7	21772.2	21849.5	21880.3
1993	8	10316	13139.9	13850.3	14214.7	14225.1	14468.5	14556.8	380.5	1955.3	2096.9	3075.1	3119.9	3196.1	25889.3	25981.3	26017.9
1993	9	17189.1	21894.5	23078.2	23685.4	23702.7	24108.3	24255.4	932.1	4789.7	5136.7	7532.8	7642.7	7829.2	43138.4	43291.5	43352.5
1993	10	10919.5	13908.6	14660.6	15046.3	15057.3	15315	15408.4	298.4	1533.5	1644.6	2411.7	2446.9	2506.6	27404	27501.3	27540
1993	11	12388.4	15779.7	16632.8	17070.4	17082.9	17375.2	17481.2	625.8	3215.9	3448.8	5057.6	5131.4	5256.7	31090.5	31200.9	31244.8
1993	12	7802.9	9939	10476.3	10751.9	10759.8	10943.9	11010.7	302.3	1553.7	1666.2	2443.5	2479.1	2539.6	19582.6	19652.1	19679.8
1994	1	4630.7	5898.3	6217.2	6380.8	6385.4	6494.7	6534.3	184.8	949.6	1018.4	1493.4	1515.2	1552.2	11621.4	11662.6	11679
1994	2	2645.4	3369.6	3551.8	3645.2	3647.9	3710.3	3733	84.6	434.9	466.4	684	694	710.9	6639.1	6662.7	6672.1
1994	3	5149.5	6559.1	6913.7	7095.6	7100.8	7222.3	7266.4	130.1	668.8	717.3	1051.9	1067.2	1093.2	12923.3	12969.2	12987.4
1994	4	5479.9	6979.9	7357.3	7550.9	7556.4	7685.7	7732.6	173.4	891.2	955.8	1401.7	1422.1	1456.8	13752.5	13801.3	13820.7
1994	5	26574	33848.5	35678.5	36617.2	36643.9	37271	37498.4	700.9	3601.7	3862.6	5664.5	5747.1	5887.4	66691.2	66928	67022.3
1994	6	20610.6	26252.7	27672	28400	28420.8	28907.1	29083.5	1252.2	6434.8	6901	10120.1	10267.7	10518.3	51725.2	51908.9	51982
1994	7	31831.1	40544.7	42736.7	43861.1	43893.1	44644.2	44916.6	1778.7	9140.5	9802.6	14375.4	14585	14941	79884.6	80168.2	80281.1
1994	8	19086.6	24311.4	25625.8	26300	26319.2	26769.6	26932.9	1725.7	8868.3	9510.7	13947.3	14150.7	14496.1	47900.4	48070.5	48138.2
1994	9	23261.8	29629.6	31231.5	32053.2	32076.6	32625.5	32824.6	1516.3	7792.3	8356.8	12255.1	12433.8	12737.3	58378.7	58586	58668.6
1994	10	20655.7	26310.1	27732.5	28462.1	28482.9	28970.3	29147.1	1039.9	5343.8	5730.9	8404.2	8526.8	8734.9	51838.3	52022.4	52095.7
1994	11	23250.4	29615.1	31216.2	32037.5	32060.9	32609.5	32808.5	1376.6	7074.5	7586.9	11126	11288.3	11563.8	58350.1	58557.3	58639.8
1994	12	6023.9	7672.9	8087.7	8300.5	8306.5	8448.7	8500.2	191.1	982.1	1053.3	1544.6	1567.1	1605.4	15117.7	15171.4	15192.8
1995	1	5051	6433.7	6781.5	6959.9	6965	7084.2	7127.4	105.3	541.3	580.6	851.4	863.8	884.9	12676.2	12721.2	12739.1
1995	2	5654.7	7202.6	7592	7791.7	7797.4	7930.9	7979.3	120.5	619.3	664.2	974	988.2	1012.3	14191.2	14241.5	14261.6
1995	3	4906.9	6250.1	6588	6761.3	6766.3	6882.1	6924	132.8	682.4	731.9	1073.2	1088.9	1115.5	12314.5	12358.2	12375.6
1995	4	11427.4	14555.6	15342.5	15746.2	15757.7	16027.3	16125.1	360.5	1852.6	1986.8	2913.6	2956.1	3028.3	28678.6	28780.4	28821
1995	5	13700.3	17450.7	18394.2	18878.1	18891.9	19215.2	19332.4	459.9	2363.4	2534.6	3716.9	3771.1	3863.1	34382.9	34505	34553.6
1995	6	20767.2	26452.1	27882.2	28615.8	28636.7	29126.7	29304.4	1211.2	6224.1	6675	9788.7	9931.5	10173.9	52118.1	52303.2	52376.9
1995	7	31964.7	40714.9	42916.1	44045.2	44077.4	44831.6	45105.2	2255.3	11589.8	12429.3	18227.4	18493.2	18944.6	80219.9	80504.7	80618.1
1995	8	17970.3	22889.6	24127.1	24761.9	24780	25204	25357.8	1135.2	5833.4	6256	9174.3	9308.1	9535.3	45099	45259.1	45322.9
1995	9	25926.3	33023.5	34808.9	35724.7	35750.8	36362.6	36584.4	1342	6896.7	7396.2	10846.4	11004.6	11273.2	65065.7	65296.7	65388.7
1995	10	23146.9	29483.2	31077.2	31894.8	31918.1	32464.3	32662.4	1643.6	8446.3	9058.1	13283.6	13477.3	13806.3	58090.3	58296.6	58378.7
1995	11	15011.8	19121.2	20155	20685.3	20700.4	21054.6	21183.1	623.2	3202.5	3434.4	5036.5	5110	5234.7	37674.3	37808	37861.3
1995	12	6192.9	7888.1	8314.6	8533.4	8539.6	8685.7	8738.7	313	1608.4	1725	2529.6	2566.5	2629.1	15541.9	15597	15619

Appendix 4-1. Naturalized Streamflows ... *continuation*

Year	Month	NAT CP1	NAT CP2	NAT CP3	NAT CP4	NAT CP5	NAT CP6	NAT CP7	NAT CP8	NAT CP9	NAT CP10	NAT CP11	NAT CP12	NAT CP14	NAT CP15	NAT CP16	NAT CP17
1996	1	8711	11095.6	11695.5	12003.2	12012	12217.5	12292.1	174.2	895.4	960.2	1408.2	1428.7	1463.6	21861.5	21939.2	21970.1
1996	2	8687	11065.1	11663.3	11970.2	11978.9	12183.9	12258.2	215	1105	1185.1	1737.9	1763.2	1806.2	21801.3	21878.8	21909.6
1996	3	7899.8	10062.4	10606.4	10885.4	10893.4	11079.8	11147.4	290.4	1492.3	1600.4	2347	2381.2	2439.3	19825.8	19896.2	19924.2
1996	4	20228.5	25765.9	27158.9	27873.4	27893.8	28371.1	28544.2	624.4	3208.9	3441.3	5046.6	5120.2	5245.2	50766.1	50946.4	51018.1
1996	5	18159.1	23130	24380.5	25021.9	25040.2	25468.7	25624.1	1402.6	7207.8	7729.9	11335.7	11501	11781.7	45572.7	45734.5	45798.9
1996	6	20345.9	25915.5	27316.6	28035.3	28055.8	28535.9	28710	1149.6	5907.8	6335.8	9291.3	9426.8	9656.9	51060.9	51242.2	51314.4
1996	7	20313	25873.6	27272.4	27989.9	28010.4	28489.7	28663.5	1511.2	7765.8	8328.4	12213.4	12391.5	12694	50978.3	51159.3	51231.4
1996	8	21525.3	27417.7	28900	29660.3	29682	30189.9	30374.1	1468.8	7548.1	8094.9	11871	12044.1	12338.1	54020.6	54212.4	54288.8
1996	9	12259.6	15615.6	16459.9	16892.9	16905.3	17194.6	17299.5	785.9	4038.9	4331.4	6352	6444.6	6601.9	30767.3	30876.5	30920
1996	10	16787.8	21383.3	22539.4	23132.4	23149.3	23545.4	23689.1	904.8	4649.6	4986.4	7312.5	7419.1	7600.2	42131.2	42280.8	42340.4
1996	11	12535.5	15967	16830.3	17273.1	17285.7	17581.5	17688.8	369.9	1900.7	2038.4	2989.3	3032.9	3106.9	31459.6	31571.3	31615.8
1996	12	10426.9	13281.2	13999.2	14367.5	14378	14624	14713.3	329.1	1691.1	1813.6	2659.6	2698.4	2764.3	26167.7	26260.6	26297.6
1997	1	7948.6	10124.5	10671.9	10952.7	10960.7	11148.2	11216.3	205.2	1054.5	1130.9	1658.4	1682.6	1723.7	19948.2	20019	20047.2
1997	2	3097.3	3945.1	4158.4	4267.8	4270.9	4344	4370.5	96.7	496.8	532.8	781.3	792.7	812	7773	7800.6	7811.6
1997	3	12412.1	15809.8	16664.6	17103	17115.5	17408.4	17514.6	287.7	1478.7	1585.8	2325.6	2359.5	2417.1	31149.9	31260.5	31304.5
1997	4	15695.8	19992.4	21073.3	21627.7	21643.5	22013.9	22148.2	801.2	4117.5	4415.8	6475.7	6570.1	6730.5	39390.8	39530.6	39586.3
1997	5	6352.8	8091.8	8529.3	8753.7	8760.1	8910	8964.4	248	1274.5	1366.9	2004.5	2033.7	2083.3	15943.2	15999.8	16022.3
1997	6	17215.7	21928.3	23113.9	23722	23739.3	24145.6	24292.9	809.4	4159.5	4460.8	6541.7	6637.1	6799.1	43205.1	43358.5	43419.6
1997	7	25326.7	32259.7	34003.8	34898.4	34923.9	35521.6	35738.3	597.6	3071	3293.4	4829.8	4900.2	5019.8	63560.8	63786.5	63876.3
1997	8	17013	21670.2	22841.8	23442.8	23459.9	23861.3	24006.9	936.5	4812.8	5161.4	7569.1	7679.5	7866.9	42696.5	42848.1	42908.5
1997	9	15170.8	19323.7	20368.4	20904.3	20919.6	21277.5	21407.4	660.4	3393.6	3639.4	5337.2	5415	5547.2	38073.1	38208.3	38262.2
1997	10	26993	34382.1	36241	37194.5	37221.6	37858.6	38089.6	1505.9	7738.6	8299.2	12170.6	12348.1	12649.5	67742.6	67983.1	68078.9
1997	11	12019.1	15309.2	16136.9	16561.5	16573.5	16857.2	16960	307	1577.7	1692	2481.2	2517.4	2578.8	30163.5	30270.6	30313.3
1997	12	9181.5	11694.9	12327.2	12651.5	12660.8	12877.4	12956	232.3	1193.9	1280.4	1877.7	1905.1	1951.6	23042.3	23124.1	23156.7
1998	1	3032	3862	4070.8	4177.9	4181	4252.5	4278.4	72.4	372.1	399	585.2	593.7	608.2	7609.2	7636.3	7647
1998	2	4338.9	5526.7	5825.5	5978.8	5983.1	6085.5	6122.6	130.5	670.5	719	1054.4	1069.8	1095.9	10889.2	10927.8	10943.2
1998	3	2967.1	3779.3	3983.6	4088.4	4091.4	4161.4	4186.8	70.3	361.3	387.5	568.2	576.5	590.6	7446.3	7472.7	7483.2
1998	4	7572.8	9645.8	10167.3	10434.8	10442.4	10621.1	10685.9	250.3	1286.1	1379.2	2022.6	2052.1	2102.2	19005	19072.5	19099.3
1998	5	11431.1	14560.3	15347.5	15751.3	15762.8	16032.5	16130.3	403.5	2073.5	2223.7	3261	3308.6	3389.4	28688	28789.8	28830.4
1998	6	14946.2	19037.6	20066.9	20594.8	20609.9	20962.6	21090.5	561.3	2884.6	3093.6	4536.6	4602.8	4715.1	37509.6	37642.8	37695.8
1998	7	31488.5	40108.3	42276.8	43389.1	43420.8	44163.8	44433.3	1227.8	6309.7	6766.8	9923.4	10068.1	10313.8	79024.9	79305.5	79417.2
1998	8	13632.9	17364.8	18303.6	18785.2	18798.9	19120.6	19237.2	510.5	2623.3	2813.3	4125.6	4185.8	4288	34213.6	34335	34383.4
1998	9	12838.7	16353.3	17237.4	17690.9	17703.8	18006.8	18116.6	479.6	2464.6	2643.2	3876.2	3932.7	4028.7	32220.6	32335	32380.6
1998	10	20426.7	26018.4	27425.1	28146.6	28167.2	28649.2	28824	783.4	4025.8	4317.4	6331.4	6423.7	6580.5	51263.7	51445.7	51518.2
1998	11	11972.1	15249.4	16073.9	16496.8	16508.8	16791.4	16893.8	451.7	2321.4	2489.5	3650.9	3704.1	3794.5	30045.8	30152.4	30194.9
1998	12	8971.3	11427.1	12044.9	12361.8	12370.8	12582.5	12659.3	330.2	1696.7	1819.6	2668.4	2707.3	2773.4	22514.6	22594.6	22626.4

Appendix 4-2. Parallel Manual Calculation of Naturalized Flows (NF)

Formulas:

At Gauged Control Point:

NF = Observed flow - Flow adjustment

At Ungauged Control Point:

$NF = NF_{gauged\ cp} * \text{Drainage Area Ratio}$

where:

$$\text{Drainage Area Ratio (DAR)} = \frac{\text{Area}_{ungauged\ cp}}{\text{Area}_{gauged\ cp}}$$

Control Point (CP)		Drainage area (ha)	Drainage Area Ratio
Oroua River			
Source/Gauged CP:	CP3	30,439.96	
Ungauged CP:			
	CP1	22,671.80	0.74
	CP2	28,878.07	0.95
	CP4	31,240.20	1.03
	CP5	31,263.02	1.03
	CP6	31,798.01	1.04
	CP7	31,992.01	1.05
	CP15	56,898.05	1.87
	CP16	57,100.06	1.88
	CP17	57,180.51	1.88
Kiwitea Stream			
Source/Gauged CP:	CP12	23,860.75	
Ungauged CP:	CP8	2,909.89	0.12
	CP9	14,953.69	0.63
	CP10	16,036.89	0.67
	CP11	23,517.77	0.99
	CP13	24,287.58	1.02
	CP14	24,443.16	1.02

Appendix 4-3. Flow-Frequency for Naturalized Streamflows* Developed with WRAP

CONTROL POINT	MEAN	STANDARD DEVIATION	PERCENTAGE OF MONTHS WITH FLOWS EQUALING OR EXCEEDING VALUES SHOWN IN THE TABLE 100%	99%	98%	95%	90%	75%	60%	50%	40%	25%	10%	MAXIMUM
CP1	13877.6	7472.4	2645.4	2877	2995.7	3842.3	5070.7	7948.6	11326	12412	15145	20229	24914	31965
CP2	17676.6	9517.9	3369.6	3664.6	3815.7	4894.1	6458.8	10124.5	14426	15810	19290	25766	31734	40715
CP3	18632.2	10032.5	3551.8	3862.7	4022	5158.7	6807.9	10671.9	15206	16665	20333	27159	33449	42916
CP4	19122.4	10296.4	3645.2	3964.3	4127.8	5294.4	6987	10952.7	15606	17103	20868	27873	34329	44045
CP5	19136.4	10303.9	3647.9	3967.2	4130.8	5298.2	6992.2	10960.7	15618	17116	20883	27894	34354	44077
CP6	19463.9	10480.3	3710.3	4035.1	4201.5	5388.9	7111.8	11148.2	15885	17408	21241	28371	34942	44832
CP7	19582.6	10544.2	3733	4059.7	4227.1	5421.8	7155.2	11216.3	15982	17515	21370	28544	35156	45105
CP8	643.2	518.2	70.3	71.8	77.8	101.9	131	248	354	460	625	937	1498	2255
CP9	3305.1	2662.7	361.3	369.1	399.7	523.5	672.9	1274.5	1821	2363	3210	4813	7701	11590
CP10	3544.5	2855.6	387.5	395.8	428.7	561.5	721.6	1366.9	1953	2535	3443	5161	8258	12429
CP11	5198	4187.7	568.2	580.4	628.7	823.4	1058.2	2004.5	2865	3717	5049	7569	12111	18227
CP12	5273.8	4248.8	576.5	588.9	637.8	835.4	1073.6	2033.7	2906	3771	5122	7680	12287	18493
CP14	5402.5	4352.5	590.6	603.3	653.4	855.7	1099.8	2083.3	2977	3863	5248	7867	12587	18945
CP15	34827.9	18753	6639.1	7220.3	7518	9642.7	12725.6	19948.2	28424	31150	38007	50766	62524	80220
CP16	34951.5	18819.5	6662.7	7245.9	7544.7	9676.9	12770.8	20019	28525	31261	38142	50946	62746	80505
CP17	35000.8	18846.1	6672.1	7256.1	7555.3	9690.6	12788.8	20047.2	28565	31305	38196	51018	62835	80618

* flow unit is acre-ft/mo

Appendix 4-4. Sample Parallel Manual Calculation of Current Water Allocation*

Period: February 1998

Based on Full Permitted Rates

					Sequence of Water Allocation & Abstraction Rates											
					After MWC-912876 63.9		After WR-100790 221.9		After WR-4514 16.8		After IF1a 1949.4		After WR-3600 23.7		After WR-3675 32.6	
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U	4338.9	*4338.9*	4274.9	4274.9										
CP2	WR-100790	p	5526.6	5526.6	5462.7	**5462.7**	5240.8	5240.8								
CP3	WR-4514	s t	5825.5	5825.5	5761.6	5761.6	5539.7	**5539.7**	5522.8	5522.8						
CP3	WR-3600	r	5825.5	5825.5	5761.6	5761.6	5539.7	5539.7	5522.8	5522.8	5522.8	**3573.4**	5499.2	3549.8		
CP4	WR-3675	e	5978.7	5978.7	5914.7	5914.7	5692.8	5692.8	5676.0	5676.0	5676.0	3726.6	5652.3	**3702.9**	5619.8	3670.4
CP5	WR-4586	a	5983.0	5983.0	5919.1	5919.1	5697.2	5697.2	5680.4	5680.4	5680.4	3730.9	5656.7	3707.3	5624.1	**3674.7**
CP6	WR-4487	m	6085.4	6085.4	6021.5	6021.5	5799.6	5799.6	5782.7	5782.7	5782.7	3833.3	5759.1	3809.7	5726.5	3777.1
CP6	WR-4447	t	6085.4	6085.4	6021.5	6021.5	5799.6	5799.6	5782.7	5782.7	5782.7	3833.3	5759.1	3809.7	5726.5	3777.1
CP7	WR-MWT820019	o	6122.5	6122.5	6058.6	6058.6	5836.7	5836.7	5819.9	5819.9	5819.9	3870.5	5796.2	3846.8	5763.6	3814.2
CP 8	WR-6092		130.5	*130.5*												
CP9	WR-MWC912875	D o	670.4	670.4												
CP10	WR-701526	w	719.0	719.0												
CP11	WR-6273	n	1054.4	1054.4												
CP12	Kiwitea St	s	1069.8	1069.8												
CP14	WR-4796	t	1095.9	1095.9												
CP15	WR-6105	r e	10889.0	10889.0	10825.1	10825.1	10603.1	10603.1	10586.3	10586.3	10586.3	8636.9	10562.6	8613.2	10530.1	8580.7
CP16	WR-MWT690185	a	10927.6	10927.6	10863.7	10863.7	10641.8	10641.8	10625.0	10625.0	10625.0	8675.6	10601.3	8651.9	10568.8	8619.3
CP17	Kawa Wool St	m	10943.0	10943.0	10879.1	10879.1	10657.2	10657.2	10640.4	10640.4	10640.4	8691.0	10616.7	8667.3	10584.1	8634.7

Based on Estimated Abstraction Rates

					After MWC-912876 63.7		After WR-100790 221.3		After WR-4514 16.8		After IF1a 1949.4	23393.0	After WR-3600 23.6		After WR-3675 32.5	
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U	4338.9	*4338.9*	4275.1	4275.1										
CP2	WR-100790	p	5526.6	5526.6	*5462.9*	**5462.9**	5241.6	5241.6								
CP3	WR-4514	s t	5825.5	5825.5	5761.8	5761.8	*5540.5*	**5540.5**	5523.7	5523.7						
CP3	WR-3600	r	5825.5	5825.5	5761.8	5761.8	5540.5	5540.5	5523.7	5523.7	5523.7	**3574.3**	5500.1	3550.7		
CP4	WR-3675	e	5978.7	5978.7	5914.9	5914.9	5693.6	5693.6	5676.8	5676.8	5676.8	3727.4	*5653.2*	**3703.8**	5620.8	3671.4
CP5	WR-4586	a	5983.0	5983.0	5919.3	5919.3	5698.0	5698.0	5681.2	5681.2	5681.2	3731.8	5657.6	3708.2	*5625.1*	**3675.7**
CP6	WR-4487	m	6085.4	6085.4	6021.7	6021.7	5800.4	5800.4	5783.6	5783.6	5783.6	3834.2	5760.0	3810.6	5727.5	3778.1
CP6	WR-4447	t	6085.4	6085.4	6021.7	6021.7	5800.4	5800.4	5783.6	5783.6	5783.6	3834.2	5760.0	3810.6	5727.5	3778.1
CP7	WR-MWT820019	o	6122.5	6122.5	6058.8	6058.8	5837.5	5837.5	5820.7	5820.7	5820.7	3871.3	5797.1	3847.7	5764.7	3815.2
CP 8	WR-6092		130.5	*130.5*												
CP9	WR-MWC912875	D o	670.4	670.4												
CP10	WR-701526	w	719.0	719.0												
CP11	WR-6273	n	1054.4	1054.4												
CP12	Kiwitea St	s	1069.8	1069.8												
CP14	WR-4796	t	1095.9	1095.9												
CP15	WR-6105	r e	10889.0	10889.0	10825.2	10825.2	10603.9	10603.9	10587.2	10587.2	10587.2	8637.8	10563.6	8614.1	10531.1	8581.7
CP16	WR-MWT690185	a	10927.6	10927.6	10863.9	10863.9	10642.6	10642.6	10625.8	10625.8	10625.8	8676.4	10602.2	8652.8	10569.8	8620.3
CP17	Kawa Wool St	m	10943.0	10943.0	10879.3	10879.3	10658.0	10658.0	10641.2	10641.2	10641.2	8691.8	10617.6	8668.2	10585.2	8635.7

* Upstream-to-downstream priority allocation at "usual" or high river flows; units in acre-ft/mo

Appendix 4-4. Sample Parallel Manual Calculation ... *continuation*

Period: February 1998			Sequence of Water Allocation & Abstraction Rates													
Based on Full Permitted Rates			After WR-4586 172.6		After WR-4487 14.8		After WR-4447 30.2		After WT820019 6.4		After WR-6092 1.0		After MWC-912875 18.9		After MWT701526 10.7	
Control Point	Water Right	Priority	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U														
CP2	WR-100790	ps														
CP3	WR-4514	t														
CP3	WR-3600	r														
CP4	WR-3675	e														
CP5	WR-4586	a	5451.5	3502.1												
CP6	WR-4487	m	5553.9	**3604.5**	5539.1	3589.7										
CP6	WR-4447	t	5553.9	3604.5	5539.1	**3589.7**	5508.9	3559.5								
CP7	WR-MWT820019	o	5591.0	3641.6	5576.2	3626.8	5546.0	**3596.6**	5539.6	3590.2						
CP 8	WR-6092										129.4	129.4				
CP9	WR-MWC912875	D									669.4	**669.4**	650.4	650.4		
CP10	WR-701526	ow									717.9	717.9	699.0	**699.0**	688.4	688.4
CP11	WR-6273	n									1053.3	1053.3	1034.4	1034.4	1023.7	**1023.7**
CP12	Kiwitea St	s									1068.7	1068.7	1049.8	1049.8	1039.1	1039.1
CP14	WR-4796	t									1094.8	1094.8	1075.9	1075.9	1065.2	1065.2
CP15	WR-6105	re	10357.5	8408.1	10342.7	8393.3	10312.5	8363.1	10306.1	8356.7	10305.1	8355.6	10286.1	8336.7	10275.5	8326.0
CP16	WR-MWT690185	a	10396.1	8446.7	10381.3	8431.9	10351.1	8401.7	10344.7	8395.3	10343.7	8394.3	10324.8	8375.4	10314.1	8364.7
CP17	Kawa Wool St	m	10411.5	8462.1	10396.7	8447.3	10366.5	8417.1	10360.1	8410.7	10359.1	8409.7	10340.2	8390.8	10329.5	8380.1

Based on Estimated Abstraction Rates			After WR-4586 172.1		After WR-4487 14.8		After WR-4447 30.1		After WT820019 6.4		After WR-6092 1.0		After MWC-912875 18.9		After MWT701526 10.6	
Control Point	Water Right	Priority	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U														
CP2	WR-100790	ps														
CP3	WR-4514	t														
CP3	WR-3600	r														
CP4	WR-3675	e														
CP5	WR-4586	a	5453.0	3503.6												
CP6	WR-4487	m	*5555.4*	**3606.0**	5540.7	3591.2										
CP6	WR-4447	t	5555.4	3606.0	*5540.7*	**3591.2**	5510.5	3561.1								
CP7	WR-MWT820019	o	5592.5	3643.1	5577.8	3628.4	*5547.7*	**3598.2**	5541.3	3591.9						
CP 8	WR-6092										129.4	129.4				
CP9	WR-MWC912875	D									*669.4*	**669.4**	650.5	650.5		
CP10	WR-701526	ow									718.0	718.0	**699.1**	*699.1*	688.4	688.4
CP11	WR-6273	n									1053.3	1053.3	1034.5	1034.5	*1023.8*	**1023.8**
CP12	Kiwitea St	s									1068.7	1068.7	1049.8	1049.8	1039.2	1039.2
CP14	WR-4796	t									1094.8	1094.8	1075.9	1075.9	1065.3	1065.3
CP15	WR-6105	re	10359.0	8409.6	10344.2	8394.8	10314.1	8364.7	10307.7	8358.3	10306.7	8357.3	10287.8	8338.4	10277.2	8327.8
CP16	WR-MWT690185	a	10397.6	8448.2	10382.9	8433.5	10352.8	8403.3	10346.4	8397.0	10345.4	8395.9	10326.5	8377.1	10315.9	8366.4
CP17	Kawa Wool St	m	10413.0	8463.6	10398.3	8448.9	10368.2	8418.7	10361.8	8412.4	10360.8	8411.3	10341.9	8392.5	10331.2	8381.8

* Upstream-to-downstream priority allocation at "usual" or high river flows; units in acre-ft/mo

Appendix 4-4. Sample Parallel Manual Calculation ... *continuation*

Period: February 1998

Based on Full Permitted Rates

			Sequence of Water Allocation & Abstraction Rates										
			After WR-6273 64.1		After IF2 202.4		After WR-4796 0.8		After WR-6105 5.6		After MWT690185 168.2		Unappropriated Flow
Control Point	Water Right	Priority	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	
CP1	MWC912876	U											3502.1
CP2	WR-100790	p s											3502.1
CP3	WR-4514	t											3502.1
CP3	WR-3600	r											3502.1
CP4	WR-3675	e											3502.1
CP5	WR-4586	a											3502.1
CP6	WR-4487	m											3559.5
CP6	WR-4447	t											3559.5
CP7	WR-MWT820019	o											3590.2
CP 8	WR-6092												129.4
CP9	WR-MWC912875	D											650.4
CP10	WR-701526	o w											688.4
CP11	WR-6273	n	959.6	959.6									772.6
CP12	Kiwitea St	s	975.0	975.0	975.0	772.6							772.6
CP14	WR-4796	t	1001.1	1001.1	1001.1	**798.7**	1000.4	798.0					798.0
CP15	WR-6105	r e	10211.3	8261.9	10211.3	8059.5	10210.6	**8261.2**	10205.0	8255.6			8126.1
CP16	WR-MWT690185	a	10250.0	8300.6	10250.0	8098.2	10249.3	8299.8	10243.7	**8294.2**	10075.5	8126.1	8126.1
CP17	Kawa Wool St	m	10265.4	8316.0	10265.4	8113.6	10264.7	8315.2	10259.1	8309.6	10093.9	**8141.5**	8141.5

Based on Estimated Abstraction Rates

			After WR-6273 63.9		After IF2 202.4 2429.0		After WR-4796 0.7		After WR-6105 5.6		After MWT690185 167.7		Unappropriated Flow
Control Point	Water Right	Priority	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	
CP1	MWC912876	U											3503.6
CP2	WR-100790	p s											3503.6
CP3	WR-4514	t											3503.6
CP3	WR-3600	r											3503.6
CP4	WR-3675	e											3503.6
CP5	WR-4586	a											3503.6
CP6	WR-4487	m											3561.1
CP6	WR-4447	t											3561.1
CP7	WR-MWT820019	o											3591.9
CP 8	WR-6092												129.4
CP9	WR-MWC912875	D											650.5
CP10	WR-701526	o w											688.4
CP11	WR-6273	n	959.9	959.9									772.9
CP12	Kiwitea St	s	975.3	975.3	975.3	772.9							772.9
CP14	WR-4796	t	1001.4	1001.4	1001.4	**799.0**	1000.6	798.2					798.2
CP15	WR-6105	r e	10213.3	8263.8	10213.3	8061.4	*10212.5*	**8263.1**	10206.9	8257.5			8128.5
CP16	WR-MWT690185	a	10251.9	8302.5	10251.9	8100.1	10251.2	8301.8	*10245.6*	**8296.2**	10077.9	8128.5	8128.5
CP17	Kawa Wool St	m	10267.3	8317.9	10267.3	8115.5	10266.6	8317.2	10261.0	8311.6	*10093.3*	**8143.9**	8143.4

* Upstream-to-downstream priority allocation at "usual" or high river flows; units in acre-ft/mo

Appendix 4-5. Reliability Summary for Selected Control Points Under Allocation Based on Full Permitted Rates

Name	Target Diversion (ac-ft/yr)	Mean Shortage (ac-ft/yr)	Reliability Period (%)	Reliability Volume (%)	Percentage of Months With Diversion Equaling or Exceeding Percentage of Target Diversion Amount 100%	95%	90%	75%	50%	25%	>0%	Percentage of Years With Diversion Equaling or Exceeding Percentage of Target Diversion Amount 100%	98%	95%	90%	75%	50%	>0%
CP1	767	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP2	2663	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP3	486	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP4	391	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP5	2071	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP6	540	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP7	77	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP8	13	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP9	227	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP10	128	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP11	769	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP12	0	0	There are no diversions at this control point															
CP14	10	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP15	67	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP16	2018	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CP17	0	0	There are no diversions at this control point															
Total	10228	0		100														

Appendix 4-6a. WRAP Model for Oroua Water Allocation Based on Monthly Flow Threshold

T1	WRAP-SIM Input File for Oroua Water Allocation Management Based on Monthly Flow Threshold							
T2	Oroua WRAP-SIM Input File: simi2mt.dat							
**								
FO			-1					
JD		6	1993	1	-1	-1		0
**	Control Point (CP) records							
CP	CP1	CP2				7	NONE	
CP	CP2	CP3				7	NONE	
CP	CP3	CP4				1	NONE	
CP	CP4	CP5				7	NONE	
CP	CP5	CP6				7	NONE	
CP	CP6	CP7				7	NONE	
CP	CP7	CP15				7	NONE	
CP	CP8	CP9				7	NONE	
CP	CP9	CP10				7	NONE	
CP	CP10	CP11				7	NONE	
CP	CP11	CP12				7	NONE	
CP	CP12	CP14				1	NONE	
CP	CP14	CP15				7	NONE	
CP	CP15	CP16				7	NONE	
CP	CP16	CP17				7	NONE	
CP	CP17	OUT				7	NONE	
**	Water Right (WR) and Instream Flow (IF) records							
**	Using type 0 IF computation (i.e., IF shortages determined only)							
**	Rights granted after 21 Apr 1994 are suspended							
WR	CP1		767		1			WR-MWC912876
WR	CP2		2663		1			WR-100790
WR	CP3		0		1			WR-4514
IF	CP3		23393		1	0	IF3	
WR	CP3		284		1			WR-3600
IF	CP4		23393		1	0	IF4	
WR	CP4		391		1			WR-3675
IF	CP5		23393		1	0	IF5	
WR	CP5		0		1			WR-4586
IF	CP6		23393		1	0	IF6	
WR	CP6		0		1			WR-4487
WR	CP6		0		1			WR-4447
IF	CP7		23393		1	0	IF7	
WR	CP7		77		1			WR-MWT820019
WR	CP8		0		1			WR-6092
WR	CP9		227		1			WR-MWC912875
WR	CP10		128		1			WR-MWT701526
WR	CP11		0		1			WR-6273
IF	CP12		2429		2	0	IF12	
IF	CP14		2429		2	0	IF14	
WR	CP14		0		1			WR-4796
IF	CP15		23393		1	0	IF15	
WR	CP15		0		1			WR-6105
IF	CP16		23393		1	0	IF16	
WR	CP16		2018		1			WR-MWT690185
IF	CP17		23393		1	0	IF17	
**	End of Records							
ED								

Appendix 4-6b. WRAP Model for Oroua Water Allocation Based on Minimum Flow

T1	WRAP-SIM Inpt File for Oroua Water Allocation Management Based on Minimum Flows						
T2	Oroua WRAP-SIM Input File: simi2mn.dat						
**							
FO		-1					
JD	6	1993	1	-1	-1		0
**	Control Point (CP) records						
CP	CP1	CP2			7	NONE	
CP	CP2	CP3			7	NONE	
CP	CP3	CP4			1	NONE	
CP	CP4	CP5			7	NONE	
CP	CP5	CP6			7	NONE	
CP	CP6	CP7			7	NONE	
CP	CP7	CP15			7	NONE	
CP	CP8	CP9			7	NONE	
CP	CP9	CP10			7	NONE	
CP	CP10	CP11			7	NONE	
CP	CP11	CP12			7	NONE	
CP	CP12	CP14			1	NONE	
CP	CP14	CP15			7	NONE	
CP	CP15	CP16			7	NONE	
CP	CP16	CP17			7	NONE	
CP	CP17	OUT			7	NONE	
**	Water Right (WR) and Instream Flow (IF) records						
**	Using type 0 IF computation (i.e., IF shortages determined only)						
**	Reduced abstraction rates of municipal rights & suspended rights for irrigation purposes						
WR	CP1	332		1			WR-MWC912876
WR	CP2	2173		1			WR-100790
WR	CP3	0		1			WR-4514
IF	CP3	23393		1	0	IF3	
WR	CP3	128		1			WR-3600
IF	CP4	23393		1	0	IF4	
WR	CP4	0		1			WR-3675
IF	CP5	23393		1	0	IF5	
WR	CP5	0		1			WR-4586
IF	CP6	23393		1	0	IF6	
WR	CP6	0		1			WR-4487
WR	CP6	0		1			WR-4447
IF	CP7	23393		1	0	IF7	
WR	CP7	0		1			WR-MWT820019
WR	CP8	0		1			WR-6092
WR	CP9	128		1			WR-MWC912875
WR	CP10	0		1			WR-MWT701526
WR	CP11	0		1			WR-6273
IF	CP12	2429		2	0	IF12	
IF	CP14	2429		2	0	IF14	
WR	CP14	0		1			WR-4796
IF	CP15	23393		1	0	IF15	
WR	CP15	0		1			WR-6105
IF	CP16	23393		1	0	IF16	
WR	CP16	0		1			WR-MWT690185
IF	CP17	23393		1	0	IF17	
**	End of Records						
ED							

Appendix 4-7. Sample Parallel Manual Calculation of Water Allocation Based Monthly Flow Thresholds and Minimum Flows

Period: February 1998

Sequence of Water Allocation & Abstraction Rates

Based on Monthly Flow Thresholds*

					After MWC-912876 63.9		After WR-100790 221.9		After WR-4514 0.0		After IF1a 1949.5		After WR-3600 23.7		After WR-3675 32.6	
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U	4338.9	4338.9	4274.9	4274.9										
CP2	WR-100790	p	5526.6	5526.6	5462.7	**5462.7**	5240.8	5240.8								
CP3	WR-4514	s t	5825.5	5825.5	5761.6	5761.6	5539.7	**5539.7**	5539.7	5539.7						
CP3	WR-3600	r	5825.5	5825.5	5761.6	5761.6	5539.7	5539.7	5539.7	5539.7	5539.7	**3590.2**	5516.0	3566.5		
CP4	WR-3675	e	5978.7	5978.7	5914.7	5914.7	5692.8	5692.8	5692.8	5692.8	5692.8	3743.4	5669.1	**3719.7**	5636.6	3687.1
CP5	WR-4586	a	5983.0	5983.0	5919.1	5919.1	5697.2	5697.2	5697.2	5697.2	5697.2	3747.7	5673.5	3724.0	5641.0	**3691.5**
CP6	WR-4487	m	6085.4	6085.4	6021.5	6021.5	5799.6	5799.6	5799.6	5799.6	5799.6	3850.1	5775.9	3826.4	5743.3	3793.9
CP6	WR-4447	t	6085.4	6085.4	6021.5	6021.5	5799.6	5799.6	5799.6	5799.6	5799.6	3850.1	5775.9	3826.4	5743.3	3793.9
CP7	WR-MWT820019	o	6122.5	6122.5	6058.6	6058.6	5836.7	5836.7	5836.7	5836.7	5836.7	3887.2	5813.0	3863.6	5780.5	3831.0
CP 8	WR-6092		130.5	130.5												
CP9	WR-MWC912875	D	670.4	670.4												
CP10	WR-701526	o w	719.0	719.0												
CP11	WR-6273	n	1054.4	1054.4												
CP12	Kiwitea St	s	1069.8	1069.8												
CP14	WR-4796	t	1095.9	1095.9												
CP15	WR-6105	r e	10889.0	10889.0	10825.1	10825.1	10603.1	10603.1	10603.1	10603.1	10603.1	8653.7	10579.5	8630.0	10546.9	8597.5
CP16	WR-MWT690185	a	10927.6	10927.6	10863.7	10863.7	10641.8	10641.8	10641.8	10641.8	10641.8	8692.3	10618.1	8668.7	10585.6	8636.1
CP17	Kawa Wool St	m	10943.0	10943.0	10879.1	10879.1	10657.2	10657.2	10657.2	10657.2	10657.2	8707.7	10633.5	8684.1	10601.0	8651.5

Based on Minimum Flows**

					After MWC-912876 27.7		After WR-100790 181.1		After WR-4514 0.0		After IF1a 1949.5		After WR-3600 10.7		After WR-3675 0.0	
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U	4338.9	4338.9	4311.2	4311.2										
CP2	WR-100790	p	5526.6	5526.6	5498.9	**5498.9**	5317.8	5317.8								
CP3	WR-4514	s t	5825.5	5825.5	5797.8	5797.8	5616.7	**5616.7**	5616.7	5616.7						
CP3	WR-3600	r	5825.5	5825.5	5797.8	5797.8	5616.7	5616.7	5616.7	5616.7	5616.7	**3667.3**	5606.1	3656.6		
CP4	WR-3675	e	5978.7	5978.7	5951.0	5951.0	5769.9	5769.9	5769.9	5769.9	5769.9	3820.4	5759.2	**3809.8**	5759.2	3809.8
CP5	WR-4586	a	5983.0	5983.0	5955.3	5955.3	5774.2	5774.2	5774.2	5774.2	5774.2	3824.8	5763.6	3814.1	5763.6	**3814.1**
CP6	WR-4487	m	6085.4	6085.4	6057.7	6057.7	5876.6	5876.6	5876.6	5876.6	5876.6	3927.2	5866.0	3916.5	5866.0	3916.5
CP6	WR-4447	t	6085.4	6085.4	6057.7	6057.7	5876.6	5876.6	5876.6	5876.6	5876.6	3927.2	5866.0	3916.5	5866.0	3916.5
CP7	WR-MWT820019	o	6122.5	6122.5	6094.8	6094.8	5913.7	5913.7	5913.7	5913.7	5913.7	3964.3	5903.1	3953.6	5903.1	3953.6
CP 8	WR-6092		130.5	130.5												
CP9	WR-MWC912875	D	670.4	670.4												
CP10	WR-701526	o w	719.0	719.0												
CP11	WR-6273	n	1054.4	1054.4												
CP12	Kiwitea St	s	1069.8	1069.8												
CP14	WR-4796	t	1095.9	1095.9												
CP15	WR-6105	r e	10889.0	10889.0	10861.3	10861.3	10680.2	10680.2	10680.2	10680.2	10680.2	8730.7	10669.5	8720.1	10669.5	8720.1
CP16	WR-MWT690185	a	10927.6	10927.6	10899.9	10899.9	10718.8	10718.8	10718.8	10718.8	10718.8	8769.4	10708.2	8758.7	10708.2	8758.7
CP17	Kawa Wool St	m	10943.0	10943.0	10915.3	10915.3	10734.2	10734.2	10734.2	10734.2	10734.2	8784.8	10723.6	8774.1	10723.6	8774.1

* Upstream-to-downstream priority allocation at "usual" or high river flows

** adopting the specified 50 lps and 20 lps maximum combined abstractions for irrigation rights held prior to 21 April 1994 and suspension of those granted after the said date along Oroua River and Kiwitea Stream, respectively

Appendix 4-7. Sample Parallel Manual Calculation ... *continuation*

Period: February 1998

Sequence of Water Allocation & Abstraction Rates

Based on Monthly Flow Thresholds*					After WR-4586		After WR-4487		After WR-4447		After WT820019		After WR-6092		After MWC-912875		After MWT701526	
					0.0		0.0		0.0		6.4		0.0		18.9		10.7	
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U	4338.9	*4338.9*														
CP2	WR-100790	p s	5526.6	5526.6														
CP3	WR-4514	t	5825.5	5825.5														
CP3	WR-3600	r	5825.5	5825.5														
CP4	WR-3675	e	5978.7	5978.7														
CP5	WR-4586	a	5983.0	5983.0	5641.0	3691.5												
CP6	WR-4487	m	6085.4	6085.4	*5743.3*	**3793.9**	5743.3	3793.9										
CP6	WR-4447	t	6085.4	6085.4	5743.3	3793.9	*5743.3*	**3793.9**	5743.3	3793.9								
CP7	WR-MWT820019	o	6122.5	6122.5	5780.5	3831.0	5780.5	3831.0	*5780.5*	**3831.0**	5774.1	3824.6						
CP 8	WR-6092		130.5	*130.5*									130.5	130.5				
CP9	WR-MWC912875	D	670.4	670.4									*670.4*	**670.4**	651.5	651.5		
CP10	WR-701526	o w	719.0	719.0									719.0	719.0	*700.0*	**700.0**	689.4	689.4
CP11	WR-6273	n	1054.4	1054.4									1054.4	1054.4	1035.4	1035.4	*1024.8*	**1024.8**
CP12	Kiwitea St	s	1069.8	1069.8									1069.8	1069.8	1050.8	1050.8	1040.2	1040.2
CP14	WR-4796	t	1095.9	1095.9									1095.9	1095.9	1076.9	1076.9	1066.3	1066.3
CP15	WR-6105	r e	10889.0	10889.0	10546.9	8597.5	10546.9	8597.5	10546.9	8597.5	10540.5	8591.1	10540.5	8591.1	10521.6	8572.1	10510.9	8561.5
CP16	WR-MWT690185	a	10927.6	10927.6	10585.6	8636.1	10585.6	8636.1	10585.6	8636.1	10579.2	8629.7	10579.2	8629.7	10560.2	8610.8	10549.6	8600.1
CP17	Kawa Wool St	m	10943.0	10943.0	10601.0	8651.5	10601.0	8651.5	10601.0	8651.5	10594.6	8645.1	10594.6	8645.1	10575.6	8626.2	10565.0	8615.5

Based on Minimum Flows*					After WR-4586		After WR-4487		After WR-4447		After WT820019		After WR-6092		After MWC-912875		After MWT701526	
					0.0		0.0		0.0		0.0		0.0		10.7		0.0	
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available
CP1	MWC912876	U	4338.9	*4338.9*														
CP2	WR-100790	p s	5526.6	5526.6														
CP3	WR-4514	t	5825.5	5825.5														
CP3	WR-3600	r	5825.5	5825.5														
CP4	WR-3675	e	5978.7	5978.7														
CP5	WR-4586	a	5983.0	5983.0	5763.6	3814.1												
CP6	WR-4487	m	6085.4	6085.4	*5866.0*	**3916.5**	5866.0	3916.5										
CP6	WR-4447	t	6085.4	6085.4	5866.0	3916.5	*5866.0*	**3916.5**	5866.0	3916.5								
CP7	WR-MWT820019	o	6122.5	6122.5	5903.1	3953.6	5903.1	3953.6	*5903.1*	**3953.6**	5903.1	3953.6						
CP 8	WR-6092		130.5	*130.5*									130.5	130.5				
CP9	WR-MWC912875	D	670.4	670.4									*670.4*	**670.4**	659.8	659.8		
CP10	WR-701526	o w	719.0	719.0									719.0	719.0	*708.3*	**708.3**	708.3	708.3
CP11	WR-6273	n	1054.4	1054.4									1054.4	1054.4	1043.7	1043.7	*1043.7*	**1043.7**
CP12	Kiwitea St	s	1069.8	1069.8									1069.8	1069.8	1059.1	1059.1	1059.1	1059.1
CP14	WR-4796	t	1095.9	1095.9									1095.9	1095.9	1085.2	1085.2	1085.2	1085.2
CP15	WR-6105	r e	10889.0	10889.0	10669.5	8720.1	10669.5	8720.1	*10669.5*	**8720.1**	10669.5	8720.1	10669.5	8720.1	10658.9	8709.4	10658.9	8709.4
CP16	WR-MWT690185	a	10927.6	10927.6	10708.2	8758.7	10708.2	8758.7	10708.2	8758.7	10708.2	8758.7	10708.2	8758.7	10697.5	8748.1	10697.5	8748.1
CP17	Kawa Wool St	m	10943.0	10943.0	10723.6	8774.1	10723.6	8774.1	10723.6	8774.1	10723.6	8774.1	10723.6	8774.1	10712.9	8763.5	10712.9	8763.5

* Upstream-to-downstream priority allocation at "usual" or high river flows

** adopting the specified 50 lps and 20 lps maximum combined abstractions for irrigation rights held prior to 21 April 1994 and suspension of those granted after the said date along Oroua River and Kiwitea Stream, respectively.

Appendix 4-7. Sample Parallel Manual Calculation ... *continuation*

Period: February 1998 — Sequence of Water Allocation & Abstraction Rates

Based on Monthly Flow Thresholds*

					After WR-6273		After IF2		After WR-4796		After WR-6105		After MWT690185		Unappropriated
					0.0		202.4		0.0		0.0		168.2		Flow
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	
CP1	MWC912876	U	4338.9	*4338.9*											3566.5
CP2	WR-100790	p	5526.6	5526.6											3566.5
CP3	WR-4514	s t	5825.5	5825.5											3566.5
CP3	WR-3600	r	5825.5	5825.5											3566.5
CP4	WR-3675	e	5978.7	5978.7											3687.1
CP5	WR-4586	a	5983.0	5983.0											3691.5
CP6	WR-4487	m	6085.4	6085.4											3793.9
CP6	WR-4447	t	6085.4	6085.4											3793.9
CP7	WR-MWT820019	o	6122.5	6122.5											3824.6
CP 8	WR-6092		130.5	*130.5*											130.5
CP9	WR-MWC912875	D o	670.4	670.4											651.5
CP10	WR-701526	w	719.0	719.0											689.4
CP11	WR-6273	n	1054.4	1054.4	1024.8	1024.8									837.8
CP12	Kiwitea St	s	1069.8	1069.8	1040.2	1040.2	1040.2	837.8							837.8
CP14	WR-4796	t	1095.9	1095.9	1066.3	1066.3	1066.3	**863.9**	1066.3	863.9					863.9
CP15	WR-6105	r e	10889.0	10889.0	10510.9	8561.5	10510.9	8359.1	10510.9	**8561.5**	10510.9	8561.5			8432.0
CP16	WR-MWT690185	a	10927.6	10927.6	10549.6	8600.1	10549.6	8397.7	10549.6	8600.1	10549.6	**8600.1**	10381.4	8432.0	8432.0
CP17	Kawa Wool St	m	10943.0	10943.0	10565.0	8615.5	10565.0	8413.1	10565.0	8615.5	10565.0	8615.5	10390.8	8447.4	8447.4

Based on Minimum Flows**

					After WR-6273		After IF2		After WR-4796		After WR-6105		After MWT690185		Unappropriated
					0.0		202.4		0.0		0.0		0.0		Flow
Control Point	Water Right	Priority	NF	CP flow	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	CP flow	Available	
CP1	MWC912876	U	4338.9	*4338.9*											3656.6
CP2	WR-100790	p	5526.6	5526.6											3656.6
CP3	WR-4514	s t	5825.5	5825.5											3656.6
CP3	WR-3600	r	5825.5	5825.5											3656.6
CP4	WR-3675	e	5978.7	5978.7											3809.8
CP5	WR-4586	a	5983.0	5983.0											3814.1
CP6	WR-4487	m	6085.4	6085.4											3916.5
CP6	WR-4447	t	6085.4	6085.4											3916.5
CP7	WR-MWT820019	o	6122.5	6122.5											3953.6
CP 8	WR-6092		130.5	*130.5*											130.5
CP9	WR-MWC912875	D o	670.4	670.4											659.8
CP10	WR-701526	w	719.0	719.0											708.3
CP11	WR-6273	n	1054.4	1054.4	1043.7	1043.7									856.7
CP12	Kiwitea St	s	1069.8	1069.8	1059.1	1059.1	1059.1	856.7							856.7
CP14	WR-4796	t	1095.9	1095.9	1085.2	1085.2	1085.2	**882.8**	1085.2	882.8					882.8
CP15	WR-6105	r e	10889.0	10889.0	10658.9	8709.4	10658.9	8507.0	*10658.9*	**8709.4**	10658.9	8709.4			8709.4
CP16	WR-MWT690185	a	10927.6	10927.6	10697.5	8748.1	10697.5	8545.7	10697.5	8748.1	10697.5	**8748.1**	10697.5	8748.1	8748.1
CP17	Kawa Wool St	m	10943.0	10943.0	10712.9	8763.5	10712.9	8561.1	10712.9	8763.5	10712.9	8763.5	*10712.9*	**8763.5**	8763.5

* Upstream-to-downstream priority allocation at "usual" or high river flows

** adopting the specified 50 lps and 20 lps maximum combined abstractions for irrigation rights held prior to 21 April 1994 and suspension of those granted after the said date along Oroua River and Kiwitea Stream, respectively.

Appendix 4-8. February 1998 Daily Flow for Oroua River at Almadale Station

Daily Mean Flow (Read: xxxx0 lps)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
165	134	126	115	107	102	99	95	94	118	174	126	108	112	113	108	101	95	142	166	271	310	342	1894	1712	586	357	267

Min 94
Mean 282
Max 1894

Appendix 4-9. Prediction Equation for old Kawa Wool Station Using Concurrent Flow Data (1971-1991 period) for the Almadale Station

Equation: Almadale flow = Kawa Wool flow *0.742984 + trans2_1 * 46.037575 + 38.903932
R-squared: 0.94671

where trans2_1 is a "quantification of month" obtained using SPSS categorical regression procedure and is related to month as shown below

Month	trans2_1
Jan	-1.64
Feb	-0.94
Mar	-0.98
Apr	-0.27
May	1.86
Jun	1.39
Jul	0.26
Aug	1.21
Sep	0.07
Oct	-0.42
Nov	-0.03
Dec	-0.52

Appendix 4-10. 1993-1998 Monthly Flow Ratios

Month	Naturalized Flow (ac-ft/mo) Almadale	Spur Rd	Kawa Wool WRAP	Kawa Wool Regression	Naturalized Flow (inch/mo) Spur	Almadale	WRAP	Regression	Flow (inch/mo) Ratio Spur/WRAP	Spur/ Regression	Almadale/ Regression	Almadale/ WRAP	DAR/FR Spur/ Regression	DAR/FR Almadale/ Regression
1	12681	3882	23821	18237	0.79	2.02	2.02	1.55	0.39	0.51	1.31	1.00	0.82	0.41
2	15886	1145	29841	22507	0.23	2.53	2.53	1.91	0.09	0.12	1.33	1.00	3.42	0.40
3	9228	1480	17335	13637	0.30	1.47	1.47	1.16	0.20	0.26	1.27	1.00	1.60	0.42
4	12419	2136	23329	17875	0.43	1.98	1.98	1.52	0.22	0.29	1.31	1.00	1.46	0.41
5	20324	3750	38178	28553	0.76	3.24	3.24	2.42	0.24	0.31	1.34	1.00	1.33	0.40
6	24859	6969	46697	34608	1.42	3.97	3.97	2.94	0.36	0.48	1.35	1.00	0.86	0.39
7	11648	2990	21880	16865	0.61	1.86	1.86	1.43	0.33	0.42	1.30	1.00	0.98	0.41
8	13851	3120	26018	15982	0.63	2.21	2.21	1.36	0.29	0.47	1.63	1.00	0.89	0.33
9	23078	7643	43352	28424	1.56	3.68	3.68	2.41	0.42	0.64	1.53	1.00	0.65	0.35
10	14661	2447	27540	17005	0.50	2.34	2.34	1.44	0.21	0.34	1.62	1.00	1.21	0.33
11	16633	5131	31245	19785	1.04	2.65	2.65	1.68	0.39	0.62	1.58	1.00	0.67	0.34
12	10476	2479	19679	11411	0.50	1.67	1.67	0.97	0.30	0.52	1.72	1.00	0.80	0.31
13	6217	1515	11679	9487	0.31	0.99	0.99	0.81	0.31	0.38	1.23	1.00	1.09	0.43
14	3551	694	6671	5827	0.14	0.57	0.57	0.49	0.25	0.29	1.14	1.00	1.46	0.46
15	6914	1067	12987	10449	0.22	1.10	1.10	0.89	0.20	0.24	1.24	1.00	1.71	0.43
16	7358	1422	13821	10974	0.29	1.17	1.17	0.93	0.25	0.31	1.26	1.00	1.34	0.42
17	35679	5748	67021	49128	1.17	5.69	5.69	4.17	0.21	0.28	1.36	1.00	1.49	0.39
18	27672	10268	51981	38312	2.09	4.41	4.41	3.25	0.47	0.64	1.36	1.00	0.65	0.39
19	42737	14585	80279	58628	2.97	6.82	6.82	4.98	0.44	0.60	1.37	1.00	0.70	0.39
20	25625	14151	48136	31763	2.88	4.09	4.09	2.70	0.70	1.07	1.52	1.00	0.39	0.35
21	31231	12434	58667	39397	2.53	4.98	4.98	3.35	0.51	0.76	1.49	1.00	0.55	0.36
22	27733	8527	52095	34598	1.74	4.42	4.42	2.94	0.39	0.59	1.51	1.00	0.71	0.35
23	31216	11288	58639	39412	2.30	4.98	4.98	3.35	0.46	0.69	1.49	1.00	0.61	0.36
24	8087	1567	15192	8195	0.32	1.29	1.29	0.70	0.25	0.46	1.85	1.00	0.91	0.29
25	6781	864	12738	10247	0.18	1.08	1.08	0.87	0.16	0.20	1.24	1.00	2.07	0.43
26	7592	988	14262	11264	0.20	1.21	1.21	0.96	0.17	0.21	1.27	1.00	1.98	0.42
27	6588	1089	12375	10010	0.22	1.05	1.05	0.85	0.21	0.26	1.24	1.00	1.60	0.43
28	15343	2956	28821	21721	0.60	2.45	2.45	1.84	0.25	0.33	1.33	1.00	1.28	0.40
29	18395	3772	34554	25863	0.77	2.93	2.93	2.20	0.26	0.35	1.34	1.00	1.19	0.40
30	27882	9931	52376	38595	2.02	4.45	4.45	3.28	0.45	0.62	1.36	1.00	0.68	0.39
31	42916	18494	80617	58773	3.76	6.85	6.85	4.99	0.55	0.75	1.37	1.00	0.55	0.39
32	24127	9309	45321	29512	1.89	3.85	3.85	2.51	0.49	0.76	1.54	1.00	0.55	0.35
33	34809	11005	65387	43978	2.24	5.55	5.55	3.74	0.40	0.60	1.49	1.00	0.70	0.36
34	31077	13478	58378	38865	2.74	4.96	4.96	3.30	0.55	0.83	1.50	1.00	0.50	0.35
35	20155	5110	37861	24253	1.04	3.22	3.22	2.06	0.32	0.50	1.56	1.00	0.83	0.34
36	8314	2567	15618	8228	0.52	1.33	1.33	0.70	0.39	0.75	1.90	1.00	0.56	0.28
37	11695	1428	21969	16724	0.29	1.87	1.87	1.42	0.16	0.20	1.31	1.00	2.04	0.41
38	11663	1764	21909	16669	0.36	1.86	1.86	1.42	0.19	0.25	1.31	1.00	1.65	0.41

Appendix 4-10. 1993-1998 Monthly Flow Ratios ... continuation

Month	Naturalized Flow (ac-ft/mo)				Naturalized Flow (inch/mo)				Flow (inch/mo) Ratio				DAR/FR	DAR/FR
	Almadale	Spur Rd	Kawa Wool WRAP	Kawa Wool Regression	Spur	Almadale	WRAP	Regression	Spur/WRAP	Spur/ Regression	Almadale/ Regression	Almadale/ WRAP	Spur/ Regression	Almadale/ Regression
39	10607	2382	19924	15342	0.48	1.69	1.69	1.30	0.29	0.37	1.30	1.00	1.12	0.41
40	27158	5120	51016	37389	1.04	4.33	4.33	3.18	0.24	0.33	1.36	1.00	1.27	0.39
41	24381	11501	45798	33696	2.34	3.89	3.89	2.86	0.60	0.82	1.36	1.00	0.51	0.39
42	27317	9427	51314	37464	1.92	4.36	4.36	3.18	0.44	0.60	1.37	1.00	0.69	0.39
43	27272	12392	51230	37353	2.52	4.35	4.35	3.17	0.58	0.79	1.37	1.00	0.52	0.39
44	28901	12045	54289	35711	2.45	4.61	4.61	3.03	0.53	0.81	1.52	1.00	0.52	0.35
45	16460	6445	30920	19057	1.31	2.63	2.63	1.62	0.50	0.81	1.62	1.00	0.51	0.33
46	22539	7419	42339	27147	1.51	3.60	3.60	2.31	0.42	0.65	1.56	1.00	0.64	0.34
47	16831	3033	31616	19723	0.62	2.69	2.69	1.68	0.23	0.37	1.60	1.00	1.13	0.33
48	13999	2748	26297	15819	0.56	2.23	2.23	1.34	0.25	0.42	1.66	1.00	1.00	0.32
49	10672	1683	20047	15261	0.34	1.70	1.70	1.30	0.20	0.26	1.31	1.00	1.58	0.41
50	4159	793	7812	6288	0.16	0.66	0.66	0.53	0.24	0.30	1.24	1.00	1.38	0.43
51	16665	2360	31304	23246	0.48	2.66	2.66	1.97	0.18	0.24	1.35	1.00	1.72	0.40
52	21073	6570	39585	28994	1.34	3.36	3.36	2.46	0.40	0.54	1.37	1.00	0.77	0.39
53	8530	2033	16022	12133	0.41	1.36	1.36	1.03	0.30	0.40	1.32	1.00	1.04	0.40
54	23114	6737	43419	31774	1.37	3.69	3.69	2.70	0.37	0.51	1.37	1.00	0.82	0.39
55	34003	4901	63874	46413	1.00	5.42	5.42	3.94	0.18	0.25	1.38	1.00	1.65	0.39
56	22842	7680	42907	27557	1.56	3.64	3.64	2.34	0.43	0.67	1.56	1.00	0.62	0.34
57	20368	5415	38261	24317	1.10	3.25	3.25	2.07	0.34	0.53	1.57	1.00	0.78	0.34
58	36241	12349	68078	45588	2.51	5.78	5.78	3.87	0.43	0.65	1.49	1.00	0.64	0.36
59	16137	2518	30312	18790	0.51	2.57	2.57	1.60	0.20	0.32	1.61	1.00	1.30	0.33
60	12327	1905	23156	13569	0.39	1.97	1.97	1.15	0.20	0.34	1.71	1.00	1.24	0.31
61	4071	594	7647	6377	0.12	0.65	0.65	0.54	0.19	0.22	1.20	1.00	1.87	0.44
62	5826	1070	10943	8532	0.22	0.93	0.93	0.72	0.23	0.30	1.28	1.00	1.39	0.42
63	3984	577	7483	6179	0.12	0.64	0.64	0.52	0.18	0.22	1.21	1.00	1.87	0.44
64	10167	2052	19098	14315	0.42	1.62	1.62	1.22	0.26	0.34	1.33	1.00	1.21	0.40
65	15348	3308	28830	21310	0.67	2.45	2.45	1.81	0.27	0.37	1.35	1.00	1.12	0.39
66	20067	4603	37695	27673	0.94	3.20	3.20	2.35	0.29	0.40	1.36	1.00	1.05	0.39
67	42276	10069	79415	57548	2.05	6.74	6.74	4.89	0.30	0.42	1.38	1.00	1.00	0.39
68	18304	4186	34383	21449	0.85	2.92	2.92	1.82	0.29	0.47	1.60	1.00	0.89	0.33
69	17237	3933	32380	20103	0.80	2.75	2.75	1.71	0.29	0.47	1.61	1.00	0.89	0.33
70	27425	6424	51517	33723	1.31	4.38	4.38	2.86	0.30	0.46	1.53	1.00	0.91	0.35
71	16074	3704	30194	18705	0.75	2.56	2.56	1.59	0.29	0.47	1.61	1.00	0.88	0.33
72	12045	2707	22626	13189	0.55	1.92	1.92	1.12	0.29	0.49	1.72	1.00	0.85	0.31
					average				**0.32**	**0.47**	**1.43**	**1.00**	**0.90**	**0.37**

DAR - Drainage Area Ratio

FR - Flow Ratio

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