# WATER ACCOUNTING IN THE OROUA RIVER CATCHMENT

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**SANTIAGO T. RECILE**


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# ABSTRACT

With growing population and limited water resources, there is an increasing need worldwide for better management of water resources. This is especially true when all–or nearly all–water resources are allocated to various uses. Effective strategies for obtaining more productivity while maintaining or improving the environment must be formulated. This can be achieved only after the water quantity, quality and uses have been understood and evaluated. One tool to analyse the situation in order to gain a deeper understanding and possibly identify opportunities for better water management is the recently–proposed methodology of water accounting, which considers components of the water balance and classifies them according to uses and productivity of these uses. Identified changes in quantity and quality of water can provide important clues on increasing water productivity.

The water accounting methodology was tried in the Oroua River Catchment to evaluate its use as a way of assessing water availability, and to identify opportunities for water savings in the catchment. The use of the methodology in a basin-wide water assessment was not successful due to insufficient rainfall data–especially at the State Forest Park where most of the streamflow (approximately 80%) comes from during low flows. In addition, the monthly climatic water balance model used failed to produce a reliable estimate of streamflow. The volume of estimated streamflow was greatly underestimated as compared to the actual recorded streamflow. Streamflow water accounting was able to assess the water availability in the lower portion of the Oroua River for the indicators gave a clear picture of the existing state of the river during the summer months. Water depletions from instream uses, which include waste assimilation, environmental maintenance, and free-water evaporation, comprised the largest part of the total streamflow depletions in the lower Oroua River. In some instances, combined depletion from waste assimilation and free-water evaporation was more than 3 times the available water. Depletions from offstream uses, including municipal and industrial, and irrigation abstractions

comprised only a small portion of the total streamflow depletion. However, one limitation of the approach is that it did not account for the other return flows from irrigation and M&I diversions. Despite the limitations of the study, the use of the indicators helped in understanding the situation since the Depleted Fraction ($DF_{available}$) indicator clearly showed how much further abstraction is allowed, and the use of the Process Fraction ($PF_{depleted}$) readily shows an opportunity for better use of water.

It is recommended that the pollution effect also be included in the original water accounting methodology of Molden (1997). The pollution effect of different contaminants could be quantified by their dilution factor i.e., the physical amount of water lost to pollution from the discharge of effluents is measured by the amount of upstream water which would be required to dilute it back down to the maximum allowed concentration of pollutants.

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# CHAPTER 1

# INTRODUCTION

## 1.1 The Global Scene

Water has been on the international agenda for at least the past 35 years, and in the past few years has been the focus of increasing international concern and debate as awareness grows that without an adequate supply of clean water, life and growth would cease on earth (Abu-Zeid and Lum, 1997). The concern is intimately linked to the rapid increase in population which has occurred in this century. This rate of population increase has resulted in a quadrupling of the demand for freshwater from 1940 to 1990. Recently, water withdrawals have been increasing 4-8 percent per year with the bulk of the demand arising in the developing world. Sixty–nine percent is used for agriculture, 23 percent for industry, and 8 percent for domestic uses. (Easter and Hearne, 1995).

In many parts of the world, water scarcity is becoming a perennial problem. A growing scarcity of freshwater is now a major impediment to food production, ecosystem health, social stability, and peace among nations. In 1950, only 12 countries of fewer than 20 million inhabitants faced water shortages in one form or another. By 1995, 44 countries–with a total of 733 million inhabitants had annual renewable water supplies below 1,700 cubic metres (Postel, 1996).

By far the largest demand for the world's water comes from agriculture. More than two-thirds (up to 90 percent in some estimates) of the water withdrawn from the earth's rivers, lakes and aquifers is used for irrigation. Agriculture is not only the world's largest water user in terms of volume, it is also a relatively low-value, low-efficiency and highly subsidised water user (FAO, 1995). Over the past 25 years, the expansion of irrigation has accounted for over one-half of the increase in global food production. However, it is now becoming harder to sustain this expansion. Irrigable land and water are now becoming increasingly scarce. Newly–irrigated areas are not likely the to be the major source of new food supplies; rather the focus must be on more efficient utilisation of water in existing irrigation systems (Easter and Hearne, 1995).

Besides supplying water to domestic, industrial, and agricultural users, countries are increasingly faced with major environmental problems related to the management of water resources. For example, fisheries and wetlands depend on continuous river flows of reasonable quality water, and are threatened by growing water withdrawals. There has been a dramatic increase in water pollution as a result of the combined wastes produced through industrialisation, urbanisation, and intensification of agriculture. Degradation of water quality has, at the same time, reduced the availability of water suitable for human consumption and for sustaining the biodiversity of ecosystems. In 1990, it was estimated that over one billion people lacked access to an adequate supply of clean water and 1.7 billion people did not have adequate sanitation (Abu-Zeid and Lum, 1997).

In recent years, concern for the environment has grown, with environmental objectives receiving higher priority in all aspects of economic activity. Reflecting this increased concern for the environment, the environmental impacts of water resource developments have come under closer scrutiny. In fact, in many countries, explicit consideration of environmental impacts has now become mandatory in the planning and design of water resource projects.

At present, the sustainable development of global water resources faces the following challenges: first, to meet the increasing demand due to population growth and rising per capita consumption; second, to improve water quality to provide a wholesome water supply and effective waste water management; and third, to sustain water and land resources–including biodiversity and water conservation (Rosbjerg et al. 1997).

## 1.2 New Zealand Situation

Although abundant, New Zealand's water resources are not well distributed. The eastern areas of both islands normally have dry summers and suffer seasonal soil moisture deficits, which are a major constraint on horticultural development. The best sites for hydro-electric power schemes are already used, and developing most remaining sites would conflict with other uses–thus the construction of more dams which could enable irrigation, is a remote prospect. Competition between those who wish to use the water, and those concerned with preserving the rivers in their natural state, has increased markedly since the passing of the Water and Soil Conservation Act in 1967. This legislation, operative from 1967 to 1991, sought to promote multiple use of water resources (Waugh, 1992).

The quality of New Zealand water, although generally high by world standards, varies considerably. In some catchments it has been affected by effluents from urban areas and facilities such as dairy and wood processing plants, by runoff enriched by fertiliser and animal wastes from agricultural areas, and by sediment introduced by accelerated erosion (Upton, 1994). The dairy industry is a major producer of agricultural waste in New Zealand. About half of the more than 14,000 dairy sheds discharge effluents to rivers (Hickey et al., 1989). Often, different stresses act cumulatively to produce much greater damage to the ecosystem. The result is a loss of amenities and resources, and elimination of new opportunities for new economic initiatives such as aquaculture (Daborn, 1996).

One such catchment affected by human intervention is the Oroua River Basin. In the past, water abstraction and waste assimilation have had two major effects on the Oroua River–namely, unnaturally low flows in the river during dry periods, and unacceptable water quality in the lower river at times of low flow. A recent drought caused a very low flow, prompting the Manawatu District Council to restrict water use for Feilding residents (who obtain their water from the Oroua River). Taking water and discharging to the river both have adverse impacts on the instream and amenity values of the river. Aquatic organisms are threatened by lower habitat quality. Recreational users are faced with a river of unacceptable appearance, and with water quality, which is a potential health hazard (Linklater and Dempsey, 1997).

## 1.3 Problem Statement

In today's complex economy, water resources play a key role. Sufficient supply of fresh water is a necessary condition for economic growth and development. At the same time, preservation of satisfactory water quality in rivers, lakes, reservoirs and aquifers is necessary to protect public health and ecosystems. The economic development of many countries around the world is being hindered by the increase in water demand by different users, and the decrease in water quality due to pollution. The problem is more intense in regions where droughts and floods are further affecting the balance between demand and water availability (Simonovic, 1995).

In the past, imbalances between water supply and demand have been redressed mostly by developing new water supplies. However, the limitations of this traditional supply-side approach are rapidly becoming apparent; the most accessible sources of water have now been developed, and deeper drilling or longer transfers are becoming prohibitively expensive. The answer, therefore, must lie in reducing the demand side of the equation; by improving water use efficiency, introducing conservation measures, shifting water allocations between sectors and changing individual behaviour towards water use (Kohli, 1993).

In view of the above-mentioned problems, effective strategies for obtaining more productivity while maintaining or improving the environment must be formulated. This could be achieved only after the water quantity, quality and uses are understood and evaluated. One tool which could be used to analyse the situation to gain a deeper understanding, and possibly identify opportunities for better water management, is the recently proposed methodology of water accounting. Water accounting is based on a water balance approach–which recognises that, in developing water resources for their own needs, humans change the water balance. Water accounting considers components of the water balance and classifies them according to uses and productivity of these uses. Identified changes in quantity and quality of water can provide important clues on increasing water productivity.

## 1.4 Objectives of the Study

The main objective of the study is to apply the water use accounting approach to the Oroua River Basin to identify opportunities for water savings. A river or drainage basin is selected as the logical study unit because all of the structural and non-structural alternatives, which might feasibly be considered when managing a basin's water supply, cannot be assessed when water uses such as dams and diversions are studied individually. Specifically, the study aimed to achieve the following objectives:

1. to evaluate the use of water accounting as a method of assessing water availability at the Oroua River Basin;

2. to document the extent of water depletion in the Oroua River Basin by both offstream (domestic, municipal, industrial, irrigation and other agricultural uses) and instream (wastewater assimilation, recreational uses, stream .maintenance for environmental purposes, also fish and wildlife requirements) uses; and

3. to assesswater availability in the study area in relation to these uses.

# CHAPTER II

# REVIEW OF LITERATURE

## 2.1 Introduction

Water, like any other valuable resource, can be most effectively developed, managed, and protected after its quantity, its quality, and its use have been understood and evaluated (Godwin et al., 1990). A prerequisite to any assessment of water resources is a review of currently–available data. The data to be gathered may be divided into three basic categories. These are those concerning; (1) surface water, (2) groundwater and (3) water use, and each of the three categories may be subdivided into quantity and quality data components.

Hydrologic studies of surface water runoff characteristics are based on various types of observations. The surface water information collected should include the basic elements of streamflow stage and discharge; data on temperature and meteorological elements; Water quality parameters (both chemical and biological); aquatic plants; channel-bed regime; and sediment loading. On the other hand, groundwater studies are needed to determine both the extent and the availability of each groundwater source or aquifer, the quality of the groundwater, and hydraulic interconnections with surface water (Cox, 1987).

The general term "water use" includes all forms of water utilisation by humans or as a result of human activities (Godwin et al., 1990). Specific information on water uses in a basin is a basic requirement in monitoring the basin's water balance. The data may be used both to judge the adequacy of existing water supplies and to compare supplies with perceived needs. In addition, specific data on water uses are needed in any basin-resources assessment to determine water-use trends and, along with channel-reach data on streamflow quantity and quality, to judge how uses within the basin affect the availability of water for other purposes.

Water quality concerns, especially water quality degradation and the resultant impacts on human and environmental health, have emerged in recent years as a major consideration related to water resources (Mays, 1996). With increasing human activities and water quality deterioration within river basins, the problem of water quality management is playing an increasingly important role. Information on water quality should be an integral part of any comprehensive water resources assessment. An overview of ambient water quality is occasionally all that is needed in a water resources assessment, but considerable detail also might be required, depending on known or suspected water quality problems in a basin (Koncsos et al., 1995).

This review summarised the literature on the methods of water resource assessment, focusing mainly on the water balance and the water accounting approach. The review included also literature in water use efficiency, which is very important in identifying what improvements can be made in existing water systems. Some erroneous concepts associated with efficiency also were reviewed. For instance, water which is apparently lost is not always necessarily wasted. Furthermore, an intended improvement may, in fact, have negative effects on the hydrologic system under consideration (Palacios-Velez, 1994; Willardson, 1985).

## 2.2 Classes of Water Use

Water use may be classified by the changes which it makes to the resource. The changes may be in quantity, quality or both. Based on these changes, the general classes are classified as consumptive, non- consumptive and polluting (Frederiksen, 1992). Water use, which results in a change in quantity is classified as "consumptive" while water use resulting in a reduction of quality is classified as "polluting".

Any use of water, which causes a physical removal of water from the hydrologic system is classified as consumptive. Examples of consumptive uses are: evaporation losses from reservoirs; crop irrigation; evapotranspiration through plants and vegetation in agriculture and green urban areas; evaporation from cooling processes and water used in industrial products (e.g. soft drinks and food processing); and the drinking of water.

Non-consumptive uses, on the other hand, include hydro-generation, recreation and fisheries, navigation, washing processes in industry, and cleaning in domestic uses. Hydro-generation is the major economic use that is generally classified as non-consumptive. This is true for run-of-the-river plants, but not strictly true for storage schemes where significant reservoir evaporation may occur. The same holds for in-stream uses such as recreation and fisheries; again, to the extent that changed stream flows for these purposes do not increase evaporation (Xie et al., 1993).

Pollution, while non-consumptive in a physical sense, does alter the resource and may render it unusable for subsequent consumptive uses (Frederiksen, 1992). Pollution includes changes in water quality, such as concentration of pollutants, temperature and salinity level, all of which reduce the availability of water for consumptive uses.

The most rapidly growing and, in certain places, even the largest demand for water is the environmental sector–a sector which was not even explicitly recognised as such until a few years ago (Seckler, 1996). This sector demands water for preservation in its natural state, for maintenance of wildlife habitats, for aesthetic and recreational purposes, and similar uses. Unfortunately, the environmental sector also can be a highly consumptive user of water because of streams that discharge into sinks, and large shallow water surfaces which are exposed to evaporation in rivers, lakes, and wetlands.

### 2.3 Efficiency of Water Resource Systems

Efficiency, in general, is defined as the ratio of output over input. In irrigation, perhaps the earliest definition of efficiency was that given by Israelsen (1932) cited by Bos and Wolters (1989) as: "The ratio of irrigation water transpired by the crops of an irrigation farm or project during their growth period to the water diverted from a river or other natural source into the farm or project canal or canals during the same period of time." This definition has, in fact, only been refined (that is, more specific definition such as water conveyance efficiency, water application efficiency, etc. have been added) in the years, which have passed since (Bos and Wolters, 1989).

System efficiency, as defined above, can be subdivided into the efficiency of the various components of the system; and takes into account losses during storage, conveyance and application to irrigation plots. Identifying the various components and knowing what improvements could be made is essential to making the most effective use of this vital–but scarce–resource (Palacios-Velez, 1994). Efficiency is primarily used as a measure to compare alternative irrigation facilities and operations at the farm and project level, or within an industrial process. (Frederiksen, 1992).

#### 2.3.1 Water Use Efficiency

The water use efficiency (WUE) concept is used to measure how water is used in agriculture. Scientists usually define WUE as "yield per unit of water applied or transpired" at the individual plant or field levels (Dinar, 1993). Two commonly used definitions of WUE are "yield per unit of water evapotranspired" and "yield per unit of applied water."

The rationale of yield per unit of water evapotranspired is that liquid water, which is not converted to vapour through evapotranspiration, remains completely available for other uses. Only water lost through evapotranspiration is consumed. The goal is to maximise agricultural production per unit of consumed water, which by this definition represents high efficiency. This approach considers only water quantity and ignores water quality considerations (Letey, 1993). It assumes that water is equally useful regardless of its quality.

On the other hand, crop-water production functions, which provide relationships between crop yield and quantity and quality of water are required to assess water use efficiency via the definition of yield per unit of applied water. This definition is premised on the assumption that none of the applied water, which is not used for crop production, retains its productivity.

### 2.3.2 Classical vs Effective Efficiency

Irrigation literature contains many classical efficiency terms. The basic concept of irrigation efficiency was set forth by Israelsen (1950) as cited by (Keller and Keller, 1995). In the classical model of irrigation efficiency, drainage water is treated as though it flows to an ultimate sink. It simply drops out of the system, or "disappears". The classical approach ignores the potential reuse of irrigation return flows; in other words, it fails to consider the integrated nature of a water resource system. According to Palacios-Velez (1994) it is relatively easy to make mistakes if all the water estimated as losses is considered wasted. In many cases, part of that water can be used downstream.

Keller et al. (1995) then proposed "effective irrigation efficiency" which is the beneficially–used water divided by the amount of freshwater consumed during the process of conveying and applying the water. The concept of effective efficiency accounts for the amount of freshwater effectively consumed. Freshwater is effectively consumed when it is lost by evapotranspiration, flows to a sink, or is rendered unusable due to pollution. According to Keller and Keller (1995), the concept of effective efficiency and the associated concepts of effective supply and use overcome the limitations of the classical efficiency approach. It provides a meaningful and useful tool with which to incorporate water quality implications in the strategic search for real freshwater conservation opportunities.

The amount of the actual water supply which can directly satisfy beneficial consumptive use is the effective supply. In irrigation, some fraction (leaching requirement, LR) of the irrigation supply must percolate through the root zone to hold soil salinity at an acceptable level. The more saline the water supply and the more sensitive the crop mix is to salinity, the greater the LR. The effective supply, $V_e$, is equal to the actual water supply, V, discounted for the LR.

$$V_e = (1\text{-}LR)V$$

The actual water use, U, for a region is the difference between the inflow to the region and the recoverable reusable outflow from the region. Likewise, the effective water use, $U_e$, for a region is the difference in its effective inflow, $V_{eI}$, and effective outflow, $V_{eO}$.

From the above, the effective irrigation efficiency, $E_e$, is defined as the crop consumptive use of the applied irrigation water, $U_{ci}$, divided by the effective use, $U_e$.

$$\begin{aligned} E_e &= U_{ci}/U_e \\ &= U_{ci}/(V_{eI}\text{-}V_{eO}) \\ &= (\text{CropET} - P_e)/\{(1\text{-}LR_I)V_I - (1\text{-}LR_O)V_O\} \end{aligned}$$

Where $P_e$ is the effective rainfall; the subscript I denotes an inflow and the subscript O an outflow. In other words, it is the efficiency of an irrigation system expressed in terms of the amount of water effectively consumed by the system.

### 2.3.3 Basin-Wide Impacts of Water Efficiency

The basin-wide effects of increasing irrigation efficiency may be negative as well as positive ((Willardson, 1985). A common misinterpretation of the role of irrigation efficiency in basin water management is that an increase in irrigation efficiency will automatically result in more water's being available for new uses.

The fact is that increases in irrigation efficiency in a basin may actually result in less total water's being available for downstream use. If improved efficiencies reduce upstream consumptive use, there will be more water for downstream users. In addition, if improved irrigation efficiency reduces the volume of deep percolation, the downstream water quality will be better.

On the other hand, if improved irrigation efficiency results in more upstream consumptive use of water through irrigation of more land or through better irrigation application uniformity, upstream crop yields will increase–but the quantity of water available downstream will decrease. Further, some proportion of the precipitation which falls on a basin, called "basin leaching fraction," is required to carry the naturally–accumulating salt to a salt sink. Whenever water is consumed in a basin by an irrigation project or some other extraction process, the basin leaching fraction will be reduced. Since more upstream consumption of water lowers the basin leaching fraction, the downstream water quality will inevitably decrease–unless steps are taken to reduce the salt load that must be carried by the downstream water.

The interrelationship between water diversion by users upstream and users and aquifers downstream leads to another important concept—the WUE at a basin level. *Basin water use efficiency* is the ratio of the amount of water beneficially consumed in the basin to the amount of utilisable water resource entering the basin (Xie et al., 1993).

In a river basin, WUE may be viewed differently for each of farmers, managers of an irrigation project, or a river authority. An increase in WUE is usually positive at project, irrigation network or farm level. However, at the level of an entire basin, the effect depends on specific basin hydrogeological and sub-economic characteristics. Some studies argue that a high water use efficiency leaves little room for conserving water by simply increasing efficiencies at local levels (Keller, 1992; Fredericksen, 1992) as cited by Xie et al. (1993). This implies that localised increases in WUE may have little effect on basin–wide efficiency if there is potential for reuse of the seepage and runoff losses within the basin.

### 2.3.4 "Wet" and "Dry" Water Savings

"Dry" water savings (Seckler, 1996) refers to the water saved from a water conservation technique which reduces the amount of drainage water from a particular use when this drainage water was beneficially used downstream. On the other hand, if the drainage water is flowing directly into a salt sink, the water savings from the water conservation technique are "wet" water savings, ie they are real savings.

The term "paper water" or "dry water" stems from the fact that the classical irrigation efficiency equations used in paper calculations appeared to result in water savings (Keller, Keller, and Seckler, 1996). But in fact, when farmers increased their application efficiency and extended the area irrigated using the apparent water savings, they increased their depletion at the expense of return flows relied upon by downstream users. In many cases, the total area irrigated from the available supply remained about the same. Upstream users expanded their irrigated area, while users downstream suffered. In other words, there was no real water saving.

By definition, all of the usable drainage water in a closed water basin (i.e., no usable water leaving the water basin) is already being beneficially used, and thus water efficiency measures which only reduce drainage water create only "dry" water savings. In open systems, on the other hand, usable drainage water is being lost to salt sinks–hence, reducing this loss by reducing drainage water results in "wet" water savings, a real gain in efficiency.

## 2.4 Water Resource Assessment Methodologies

Many different methodologies can be used to analyse a basin's water resource potential (Godwin et al., 1990; Molnar et al, 1988; Schwab et al., 1993).

Examples are the use of streamflow records to establish historical maximum and minimum flows; mean flows and through the use of duration curves; and an estimate of the probability that specific levels of flow will be exceeded or not met. These records could be used to evaluate the river's ability to meet present and anticipated withdrawals without the addition of reservoir storage. Similarly, the water-supply potential of undeveloped aquifers may be roughly evaluated using the initial records of groundwater levels and basic aquifer tests to determine the percentage of the resource, which can be readily recovered. However, development upstream (diversion, dams and uses) may disturb the river's natural flow to a point where these traditional methods are inadequate (Godwin et al., 1990).

### 2.4.1 Water Balance Approach

The water balance approach remains one of the basic tools for the assessment of water resources, their formation and behaviour in the region or watershed (Molnar et al., 1988). Water balance calculations are routine for large area and long data series and provide an introductory insight into the hydrological cycle of a basin. A water balance study is an application of the principle of conservation of mass, often called the continuity equation. It contains all the terms for water inputs, water outputs and water storage changes for a given volume of space and a given time interval (Falkland and Custodio, 1991). It can be expressed in the form:

$$\text{Inputs - Outputs - Increase in storage} = e$$

where $e$ is the sum of the various water balance terms and possibly terms otherwise unaccounted for. Many other forms of expressing water balances are possible. Each part of the water-budget equation may be sub-divided into as many components and sub-components as are needed. The most appropriate water expression for a given task depends on local conditions, availability and type of data and specific goals of the water balance (Orange et al., 1997).

Conceptually, the water balance approach is straightforward. Often though, many of the components of water balance are either difficult to estimate, or are not available. For example, groundwater inflows to and from an area of interest are difficult to measure. Estimates of actual crop consumptive use at a regional scale are questionable. In addition, drainage outflows are often not measured since more emphasis has been placed on knowledge of inflows to irrigation systems or municipal water supply systems (Molden, 1997). In spite of the limitations, experience has shown that even a gross estimate of water balances for use in water accounting can be quite useful to managers, farmers, and researchers. Water balance approaches have been successfully used to study water use and productivity both at basin level (Owen-Joyce and Raymond, 1996; Roberts and Roberts, 1992) and at field level (Mishra et al., 1995).

One desirable aspect of a water budget is that the relative amounts of water constituting the various parts of the hydrologic system are indicated, allowing a judgment to be made on the availability of water for utilisation and management (Godwin et al., 1990). Another benefit is that the researcher is forced to consider the amounts and kinds of changes, which may take place in the hydrological system as a consequence of water resources and pertinent human activities.

According to Dyck (1983), water balance computations could be used for the following purposes:

1. assessment of water resources with different temporal and spatial resolution;
2. monitoring and management of water resources including their protection exhaustion and contamination;
3. for crop production;
4. modelling of the hydrological cycle under man's intervention to separate man-made changes in the hydrological cycle from natural variability
5. study of various processes of the water cycle as a basis for prediction of the effect of land use changes on the water yield of the catchments for different locations and time spans, and to determine hydrological elements including

runoff formation in river basins to understand and to model the transport of nutrients, erosion processes and sediment yield;

6. provision of hydrological data as inputs and for validation of deterministic circulation models;
7. derivation of climatic and hydrological regional classifications.

#### 2.4.1.1 Methods of Computation of the Main Water Balance Components

There are two main sources of error in the calculation of a water balance. The first relates to the measurement or calculation of basic components of the water balance equation at isolated sites. The second source of errors results from variability of basin conditions which influence calculation of areal values of precipitation and evapotranspiration from point-measured data (Kostka and Holko, 1993). Only runoff values represent the areal characteristic while precipitation could be calculated as the weighted average based on data from the storage gauges.

The computation of areal precipitation from point precipitation values constitutes one of the problems in hydrology, particularly if a high spatial resolution of the precipitation field is needed (Dyck, 1983). A variety of general interpolation methods, such as simple arithmetic mean, isohyetal method and Thiessen method, are available for areal estimations (Schwab et al., 1993) as summarised below.

The simplest method of determining the areal precipitation is to take the arithmetic mean of the point rainfall recorded by the different rain gauges. However, since each gauge may not represent equal area, other methods often give greater accuracy.

In the Thiessen method of areal rainfall calculation, the location of the rain gages is plotted on a map of the watershed. Straight lines are drawn between the rain gauges, and perpendicular bisectors are then constructed on these connecting lines in such a way that the bisector enclosed areas are referred to as Thiessen polygons. All points within one polygon will be closer to its rain gage than to any of the others. The rain recorded is then considered to represent the precipitation within the appropriate polygon area. The average precipitation over a watershed is determined by using the equation

$$P = (A_1P_1 + A_2P_2 + \dots + A_nP_n)/A$$

Where: P = average depth of rainfall in a watershed

A = Watershed area

$P_1, P_2, \dots, P_n$ = represent the rainfall depth in the polygon having areas $A_1, A_2, \dots A_n$ within the watershed.

On the other hand, the Isohyetal method consists of recording the depth of rainfall at the locations of the various rain gages and plotting isohyets (lines of equal rainfall) by the same methods for locating contour lines on topographic maps. The area between the isohyetals may be measured and the average rainfall determined by the equation set out above.

For the selection of the method best suited for the computation of mean precipitation over an area, it is necessary to take into account the following factors; the requirement of the water balance, the spatial and temporal distribution of precipitation, the density and distribution of the precipitation network, the variability of precipitation events, the available data, and possibilities of practical realisation (Schwab et al., 1993; Custodio and Falkland, 1991).

It is clearly essential to have accurate estimates of evapotranspiration for the planning and operation of any irrigation system (Faulkner and Chesworth, 1989). The allocation of water supplies, the determination of system efficiencies and potential improvements in efficiencies all depend on having good estimates of basic crop evapotranspiration available. But while precipitation and runoff data are available from standard network observations, evapotranspiration is usually calculated from the water balance equation. Evapotranspiration can be measured and calculated also by (a) methods of turbulent mass (water vapor) transport, (b) method of energy balance, (c) using standard weather data and the concept of potential evapotranspiration, and (d) the soil water equation with sink term (Dyck, 1983; Shih et al., 1983; Schwab et al., 1993).

These different techniques have been developed partly in response to the availability of different types of data for estimating ET. Each method has certain advantages and limitations. Availability of specific types of data is often a limiting factor in the choice of calculation technique for practical application (Shih et al., 1983). The choice of calculation technique depends also on the intended use, and on the time scale required by the problem.

The Energy Balance Method is a well established method of estimating evapotranspiration from direct measurements taken in the field over transpiring crop (WMO, 1971) as cited by Faulkner and Chesworth (1989), and is given by

$$E = (R_n - G)/L(1+ß)$$

where: E = evapotranspiration

$R_n$ = net radiation

G = soil heat flux in the surface layer

L= latent heat of vaporisation

ß = the Bowen ratio and defined as the ratio of sensible heat to latent heat.

Some methods of calculating evapotranspiration using climatic observations set out by Hansen et al. (1980), FAO (1977) and Schwab et al. (1993) are set out below. These include the Modified Penman, Jensen-Haise, and the Blaney-Criddle method.

a) *Modified Penman Method*: The Penman method of predicting reference crop evapotranspiration is the recommended and most internationally accepted approach to be adopted in areas where data on temperature, humidity, wind and sunshine duration of radiation are available (Makhado and Butlig, 1989). Since this method considers several climatological data in the computation, it provides the most satisfactory estimate of evapotranspiration as compared to the other method. The Modified Penman equation is given by

$$E = c[WR_n + (1 - W)\, f(u)\, (e_s - e)]$$

Where: $E$ = daily evapotranspiration

$W$ = temperature related weighing factor

$c$ = day/night wind ratio modified factor

$e_s$ = saturated vapour pressure mb

$e$ = actual vapour pressure mb

$f(u) = 0.27\ (1 + 0.01u)$

where: $u$ = windrun in km/day at 2m height

$$R_n = 0.75R_s - \sigma T^4\, (0.34 - 0.044\sqrt{e})\, (0.1 + 0.9n/N)$$

Where: $R$ = Solar radiation cals/cm$^2$/day

$\sigma$ = Stephan -Boltzman constant

$T$ = mean daily temperature in degrees Kelvin

$n$ = actual sun hours

b) *Jensen-Haise Method*

$$E_{tp} = C_t\,(T - T_x)\, R_s$$

Where: $C_t = (1/C_1 + C_2C_H)$

$C_H = 50\text{mbar}/(e_2 - e_1)$

$C_1 = 38 - (2^0\text{C} \times \text{EL}/305)$

$C_2 = 7.6^0\text{C}$

$T_x$ = the intercept on the temperature axis

$T$ = temperature in $^0$C

$R_s$ = incident solar radiation in langleys/day

$e_2$, $e_1$ = saturation vapour pressures of water at the mean maximum and mean minimum temperatures, respectively, for the warmest month of the year in a given area

c) *Blaney-Criddle Method*

$$U = 25.4\,k\,\Sigma(tp/100)$$

Where: U = consumptive use of crop in mm for a given time period

K = empirical crop consumptive use coefficient

t = mean temperature in $^0$F

p = percentage of daytime hours of the year, occurring during the period.

### 2.4.1.2 Water Balance Modelling

Numerous developments have occurred in recent years, which have significantly enhanced our knowledge and the predictability of water resources. Most of these have been incorporated into computer simulation methods, which in themselves have provided insight and predictive capability (Saxton, 1983). The use of conceptual models to simulate hydrological processes in a basin is a well-known practice. An earlier example of the development of such models is given by Thornwaite (1948) as cited by (Lian, 1995). They have been widely used in a variety of hydrological problems, and a great deal of experience has been gained on how to apply such models efficiently. They incorporate a soil moisture accounting procedure, snowmelt process and a procedure for the estimation of evapotranspiration. In addition, models have been used in river basin studies to simulate surface-subsurface water transport (Bouraoui et al., 1997), nutrient (P) transport (Zollweg et al., 1995), soil erosion (De Roo and Offermans, 1995), flood forecasting (Qi et al., 1995), and water quality studies (Koncsos et al., 1995). Some of the simulation models used in basin water balance studies, including SOIL, BILAN, ANSWERS, HSPF, IWBF and WUAM models, are summarised below.

The SOIL simulation model is used to determine evapotranspiration, the usual unknown component in the water budget. This model, which was developed initially to simulate conditions in forest soils, is based on the soil depth profile. Equations for water and heat flow represent the central part of the model. The main input driving variables are air temperature and precipitation. Wind speed, air humidity and solar radiation are other important variables due to their influence on evapotranspiration (Kostka and Holko, 1993).

BILAN is a water budget model, which was developed to assess the water balance components of a basin in monthly time steps. It is a single-cell model, where the entire basin is represented as one cell (Kasparek and Novicky, 1997). This model describes the basic principles of the water balance on the ground, in the zone of aeration and in the groundwater. It has been developed both for mountainous and lowland groundwater basins. The entry data of the model are monthly series of basin precipitation, the air temperature and relative air humidity. A runoff series at the outlet from the basin is used for calibration. The model generates a monthly series of basin potential evapotranspiration, actual evaporation, percolation to the zone of aeration, groundwater recharge components of water storage in the snow cover, zone of aeration (soil), and groundwater aquifer. The total runoff consists of three components, namely direct runoff, interflow and baseflow.

Similarly, a set of simple monthly snow and water balance models has been developed by Xu et al. (1996) and applied to regional water balance studies. The models require as input monthly areal precipitation, monthly long-term average potential evapotranspiration and monthly mean air temperature. The model outputs are monthly river flow and other water balance components, such as actual evapotranspiration, slow and fast components of river flow, snow accumulation and melting.

On the other hand, ANSWERS, a distributed parameters, surface nonpoint source pollution model for long term simulation of infiltration, runoff, sediment transport and nutrient (nitrogen and phosphorus) transport and transformation, has been modified to include the simulation of water transport in the vadose and saturated zone (Bouraoui et al, 1997). It takes into account the spatial and temporal variability of crop cover and management practices, and the spatial variability of soil type and rainfall distribution. It is physically based and uses parameters, which can be easily determined from readily available soil and plant information. It has been validated at multiple scales: local scale, field scale and watershed scale. At the local scale and field scale, it predicts accurately drainage below the root zone and evaporation on different soil covers. At the watershed scale, it reproduces well the piezometric levels and trends of variation.

Liu and Wang (1989) proposed a conceptual model to simulate the hydrological processes in a drainage basin in a plain area where the vertical fluxes predominate, and where the groundwater table is very close to the surface so that the interaction between surface and groundwater should be taken into account. The model predicts the discharge at the outlet of the basin based on the input data of rainfall and pan evaporation. Additionally, it is capable of predicting groundwater table depth at each rainfall station. The advantages of the model are: (a) it uses common hydrological and meteorological data, (b) it can be applied to different sizes of drainage basins, and (c) it produces groundwater table fluctuations as well as a discharge hydrograph.

The Hydrological Simulation Program-Fortran (HSPF) is a valuable tool for planning design and prediction scenarios due to changes of land use and management practices in the river basin systems (Ng, 1989). It is developed specifically to integrate runoff from land base to receiving water components into model packages for comprehensive analysis of complex agricultural watersheds and management practices in river basin. HSPF is a deterministic model reflective of physical processes from watershed area to receiving water, using specific time interval data related to specific events. The model simulates multicomponents of runoff, sediment, pesticide nutrients, and other water quality constituents from urban, agricultural and other land uses. For quantity, the results of simulation provide the time of high flow and low flow in streams, which are important for considerations of irrigation development. For quality, it provides instream transport and transformations which are useful for assessing the environmental fate due to agricultural chemical application.

A water balance model was developed for analysing the utilisation of water from surface irrigation and rainfall within an irrigation project (Perry, 1996b). The IIMI

Water Balance Framework (IWBF) allows explicit definition of losses to seepage, operational losses, and efficiency of field application. Recycling of water through pumping from drains and from groundwater is allowed, and the resulting water balance is presented, showing flows to groundwater, outflow from drains, and also consumptive use of crops and other evaporative uses. The proposed water balance model is based on a simple gross water balance. The elements of that balance include the most common set of known or assumed data for an irrigation system–canal inflows; operational, evaporative and seepage losses; rainfall; crop consumptive use; and recycling of groundwater and drainage flows. The framework is intended for more general or diagnostic purposes including:

- understanding and quantifying the main factors in the water balance
- identifying linkages between sources, uses, and reuses
- estimating project water consumption as a basis for defining actual losses, and the productivity of water.

The Water Use Analysis Model (WUAM) places special emphasis on water demand modelling and allows the user to investigate the impacts of social, economic and policy scenarios on future water demands and water balance (Kassem, 1996). Basically, three principal components comprise the model: (a) water use; (b) water supply; and (c) water balance. Water use forecasting is the primary focus of the model and comprises its major component. Water uses include both withdrawal (consumptive) water uses and non-withdrawal (instream) water uses.

The second major section of the model concerns water supplies, which are simulated based on a time-series of natural streamflow data at selected points within the drainage basin. The third component of the model is an algorithm, which compares the projected water uses to available supplies. This comparison is performed over an extended period of (historical) hydrologic record. The model produces, among numerous other details, statistics about the severity and frequency of water shortages, if any.

### 2.4.1.3 Examples of Water Balance Components Estimation

Shih et al. (1983) used the different methods of evapotranspiration calculation–Penman, pan evaporation, thornthwaite, Blaney-Criddle, and water budget methods–to estimate the basin-wide monthly evapotranspiration in Southern Florida. The results of the study showed that the Penman method gave predictions closest to monthly basin-wide water budgets and the Thornthwaite method had the highest deviations. However, they reported that, based upon the data availability and ease of use, the pan evaporation and modified Blaney-Criddle methods could be used to estimate basin-wide monthly water allocation because those two methods predict results close to those estimated by the Penman method.

Similarly, Yin and Brook (1992) compared temperature-based potential evapotranspiration (PET) estimates with actual evapotranspiration (AET) obtained by the water balance method in a watershed with large wetlands. Results of their study showed that the temperature-based method can give reasonably accurate estimates of PET. The PET estimated by the pan evaporation, Thornthwaite, Holdridge, and Blaney-Criddle methods closely paralleled AET estimated by the water balance approach during the study period. When the PET estimates were regressed upon AET, Thornthwaite PET had the highest $R^2$ value (0.817), followed by Blaney-Criddle method (0.781), and Holdridge PET proportioned by biotemperature (0.768).

On the other hand, Owen-Joyce and Raymond (1996) approximated evapotranspiration or consumptive use by vegetation by (1) using remote-sensing techniques to identify vegetation types and calculate the area of each vegetation type and (2) multiplying the area of each vegetation type by the associated water-use rate. They also cited their previous studies (Owen-Joyce, 1986, 1987; Owen-Joyce and Kinskey, 1987) which showed that estimates of the consumptive use by vegetation calculated as the residual in a groundwater budget showed reasonable agreement with the estimates calculated as the product of areas of vegetation types determined from landsat digital-image analysis and predetermined water-use rates.

In a similar study, actual evaporative losses had been calculated and used in annual water balances for a small agricultural catchment in southern England (Roberts and Roberts, 1992). This was done on an areal basis, by calculating the evaporative losses from different land cover types–arable, grassland and forested areas, and applying those losses to the percentage areas of the land cover types, the latter having been obtained by satellite imagery. It was found that this technique improved the annual water balance of the catchment, compared with using the Penman potential evapotranspiration for the dominant land use type, particularly during dry years when the substantial soil moisture deficit would limit transpiration losses.

Stephenson (1994) made a comparison of the water balance for two topographically similar adjacent catchments near Johannesburg, South Africa, one suburban, the other natural grassland. The research was carried out to evaluate the effects of urbanisation on catchment water resources. Aspects considered were the total water runoff and loss from the catchments, with an assessment of both flood runoff and drought runoff. A mass balance within the catchment assessed groundwater related to catchment cover. The result of the project indicated that suburban development increased the surface runoff volume by a factor of four compared with an otherwise similar underdeveloped catchment. The major loss, due to evapotranspiration, was the same (67% of precipitation) for both catchments, as garden watering appeared to increase evapotranspiration in the suburb as losses were similar to the grassed natural catchment despite the large paved areas. Results showed also that the water table in the undeveloped catchment dropped more than that for the suburban one.

In South India, Rao et al. (1996) conducted a study to evaluate the influence of conservation measures on the groundwater regime in a predominantly agricultural watershed. To assess the influence of conservation measures, groundwater recharge was computed using annual water balance equation, e.g

$$P = R + E + G....$$

Where: P is annual precipitation, R is annual runoff, E is annual Evapotranspiration, and G is groundwater recharge. The balance of P-R was assumed to have gone into the soil and lost/utilised either as evapotranspiration (E) or as groundwater recharge (G). For separating E and G, the potential evapotranspiration (PE) was considered: when P-R was more than the PE, the excess was considered as groundwater recharge, and when P-R was less than, or equal to, PE, the entire amount was taken as actual evapotranspiration.

### 2.4.2 Water Accounting Approach

The water accounting approach is a recently–proposed methodology, and additional literature on the topic is not available. Hence, the following discussion on water accounting methodology is derived mainly from the System-Wide Initiative for Water Management (SWIM) paper by Molden (1997).

#### 2.4:2.1 Water Accounting Definitions

Water accounting methodology is based on a water balance approach. The art of water accounting is to classify water balance components into water use categories, which reflect the consequences of human interventions in the hydrologic cycle (Molden, 1997). Water accounting integrates water balance information with uses of water as visualised in figure 2.1. Inflows into the domain are classified into various use categories as defined below.

*Gross inflow* is total amount of water flowing into the domain from precipitation, and surface and subsurface sources.

*Net inflow* is the gross inflow plus any changes in storage. If water is removed from storage over the period of interest, net inflow is greater than gross inflow; if water is added to storage, net inflow is less than gross inflow. Net inflow water is either depleted, or flows out of the domain of interest.

*Water depletion* is a use or removal of water from the water basin, which renders it unavailable for further use. Water depletion is a key concept for water accounting, as it is often the productivity and the derived benefits per unit of water depleted which are of interest. It is extremely important to distinguish water depleted from water diverted to a service or use, because not all water diverted to use is depleted. Water is depleted by four generic processes, the first three described by Seckler (1996) and Keller and Keller (1995). A fourth type of depletion occurs when water is incorporated into a product.

The four generic processes are:

- Evaporation : water is vaporised from surfaces or transpired by plants
- Flows to sinks: water flow into a sea, saline groundwater, or other location where it is not readily or economically recovered for use
- Pollution: water quality is degraded to an extent that it is unfit for certain uses
- Incorporation into a product: by a process such as incorporation of irrigation water into plant tissues

*Process depletion* is that amount of water diverted and depleted to produce an intended good. In industry, this includes the amount of water vaporised by cooling, or converted into a product. For agriculture, it is water transpired by crops plus that amount incorporated into plant tissues.

*Non-process depletion* occurs when diverted water is depleted, but not by the process for which it was intended. For example, water diverted for irrigation is depleted by transpiration (process), and by evaporation from soil and free water surfaces (non-process). Outflows from coastal irrigation systems, and from coastal cities to the sea are considered non-process depletion. Deep percolation flows to a saline aquifer may constitute a non-process depletion if the groundwater is not readily or economically utilisable. Non-process depletion can be further classified as beneficial or non-beneficial. For example, a village community may place beneficial value on trees that consume irrigation water. In this case, the water depletion may be considered beneficial, but depletion by these trees is not the main reason why water was diverted.

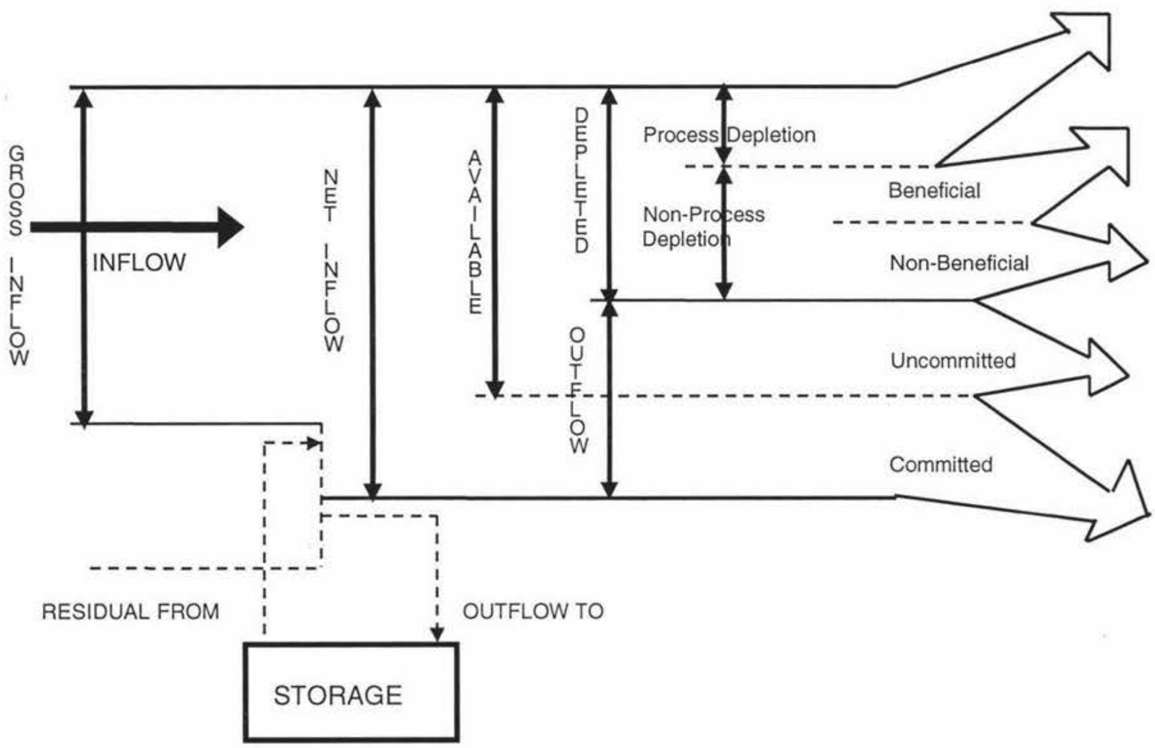



**Figure 2.1 Water Accounting (Source: Molden, 1997)**

*Committed water* is part of the outflow, which is committed to other uses. For example, downstream water rights or needs may require that a certain amount of outflow be realised from an irrigated area. Water may also be committed to environmental uses such as minimum stream flows, or outflows to sea to maintain fisheries.

*Uncommitted outflow* is water which is neither depleted, nor committed, and is thus available for use within a basin or for export to other basins, but which flows out due to lack of storage or operational measures. For example, water flowing to a sea, which is in excess of requirements for fisheries, environmental, or other beneficial uses, is uncommitted outflow. With additional storage, this uncommitted outflow can be transferred to a process use such as irrigation or urban uses.

A *closed basin* (Seckler, 1992), is one where there are no utilisable outflows in the dry season. An open basin is one where uncommitted utilisable outflows exist.

In a *fully committed basin*, there are no uncommitted outflows. All inflowing water is committed to various uses. In this case, major options for future development are reallocation among uses, or importing water into the basin.

*Available water* is the net inflow less the amount of water set aside for committed uses, and represents the amount of water available for use at the basin, service, or use levels. Available water includes process and non-process depletion, plus uncommitted water.

*Non-depletive uses of water* are uses where benefits are derived from an intended use without depleting water. In certain circumstances, hydropower can be considered a non-depletive user of water if the water diverted for another use, such as irrigation, passes through a hydropower plant. Often, a major part of instream environmental objectives can be non-depletive when outflows from these uses do not enter the sea.

### 2.4.2.2 Performance Indicators

Performance indicators for water accounting follow depleted fraction and effective efficiency concepts presented by Keller and Keller (1995). Water accounting performance indicators are presented in the form of fractions, and in terms of the productivity of water.

*Depleted Fraction* (DF) is that part of the inflow which is depleted by both process and non-process uses. Depleted fraction can be defined in terms of net, gross, and available water.

1. $$DF_{net} = \frac{\text{Depletion}}{\text{Net Inflow}}$$

2. $$DF_{gross} = \frac{\text{Depletion}}{\text{Gross Inflow}}$$

3. $$DF_{available} = \frac{\text{Depletion}}{\text{Available Water}}$$

*Process Fraction* (PF) relates process depletion to either total depletion, or the amount of available water.

4. $$PF_{depleted} = \frac{\text{Process Depletion}}{\text{Total Depletion}}$$

5. $$PF_{available} = \frac{\text{Process Depletion}}{\text{Available water}}$$

*The Process Fraction of Depleted Water* ($PF_{depleted}$) is analogous to the effective efficiency concept forwarded by Keller and Keller (1995) and is particularly useful in identifying water savings opportunities when a basin is fully or near fully committed. When there is no uncommitted water, process fraction of depleted water is equal to the process fraction of available water.

*Productivity of Water* (PW) can be related either to the physical mass or to the economic value of produce per unit volume of water. Productivity of water can be measured against gross or net inflow, depleted water, or available water. Here it is defined in terms of net inflow, depleted water, and process depletion.

6. $PW_{inflow} = \frac{\text{Productivity}}{\text{Net Inflow}}$

7. $PW_{depleted} = \frac{\text{Productivity}}{\text{Depletion}}$

8. $PW_{process} = \frac{\text{Productivity}}{\text{Process Depletion}}$

### 2.4.2.3 Levels of Analysis

Researchers in agriculture, irrigation, and water resources work with spatial scales of greatly differing magnitudes (Molden, 1997). Agricultural researchers often focus on either a field level or a plot level dealing with crop varieties and farm management practices. Irrigation specialists focus on a set of fields tied together by a common resource–water. Water resource specialists are concerned with other uses of water beyond agriculture, including municipal, industrial, and environmental uses.

An understanding of the interactions among these levels of analysis helps to understand the impacts of water management. A perceived improvement in water use at the farm level may improve overall productivity of water in a basin, or it may reduce productivity of downstream users. Only when the intervention is placed in the context of a larger scale of analysis can the answer be known. Similarly, basin–wide studies may reveal general concepts about how water can be saved or the productivity of water increased, but field–level information on how to achieve savings or increase water productivity is required. Therefore, three different levels of water use have been defined for which water accounting procedures are developed:

- Macro level: basin or subbasin level covering all or part of a water basin, including several uses of water

- Mezzo level: water services level, such as irrigation or municipal water services
- Micro level: use level such as an agricultural field, a household, or an environmental use

### 2.4.2.4 Accounting Components at Use, Service, and Basin Levels

#### 2.4.2.4.1 Field Level

The use level of analysis for irrigation is taken at the field level with inflows and outflows shown in table 2.1. This is the level where crop production takes place–the process of irrigation. Agricultural research at this level is often aimed at increasing productivity per unit of land and water and at conserving water. At the field level, the magnitudes of the components of the water balance are a function of crop and cultural practices. Different crops, and even different varieties of crops, will transpire water at different rates. For example, drip irrigation minimises these components, while surface application induces depletion by evaporation. Water accounting procedures attempt to capture the effects of different crop and cultural practices on how water is used and depleted at the field level. At this level, it is sometimes impossible, and oftentimes unnecessary, to know the fate of outflows. Only when moving up to the service and basin level can outflows be determined as being either committed or uncommitted.

#### 2.4.2.4.2 Irrigation Service Level

At the service level, the focus is on irrigation service analysis (table 2.1). Similar water accounts could be developed for municipal and industrial uses. The boundaries for an irrigation system typically include groundwater underlying the irrigated area, whereas for the field level the boundary would be taken as the bottom of the root zone. Changes in storage take place in the soil, the groundwater, and surface storage. As compared to the field level, there are more opportunities for non-process depletion, such as evaporation from free water surfaces and phreatophytes.

Water diverted primarily for irrigation often provides the source of water for other uses such as for fisheries, drinking, bathing, and industrial use. Some of this water may be committed to these uses and not available for crop transpiration. Municipal uses of irrigation service water are typically not large, but they may represent a significant proportion of depletion during low flow periods and have an important impact on operating rules. Another commitment is to ensure that water is delivered to meet downstream rights or requirements. It is very common to have downstream irrigation diversions dependent on irrigation return flows, and water rights can be violated when these outflows are not available. These outflows, whether remaining in canals or flowing through drains, can be considered committed uses of water. The water available at the irrigation service level is the diversion to irrigation less the committed uses.

#### 2.4.2.4.3 Basin and Subbasin levels

At the basin level, several process uses of water including agricultural, municipal, and industrial uses are considered (table2.1). The major inflow into a basin is precipitation. Other inflows could be river inflows into a sub-basin, trans-basin diversions, or groundwater originating from outside the water basin. At the inflow of the basin, it is important to consider commitments such as water required to remove salts and pollutants from the basin, and water required to maintain fisheries.

Through water accounting, changes in water use patterns can be analysed. For example, changes in watershed vegetation can have a profound impact on basin-wide water accounts. Reducing forest cover may reduce evaporation but induce non-utilisable, or even damaging flood flows unless surplus storage is available. Converting forest to agricultural use with water conservation practices may make water available in water-deficit seasons, or drought years. Converting from agricultural land to native vegetation may have the impact of reducing downstream flows. Using water accounting to note these factors allows decision-makers to start to understand the consequences of their actions, and to indicate where more in-depth studies would be most profitable.

**Table 2.1. Water accounting components at field, service, and basin levels (Source: Molden, 1997)**

| Field | Irrigation service | Basin/subbasin |
|---|---|---|
| **Inflow** | | |
| . irrigation application<br>. precipitation<br>. subsurface contributions<br>. surface seepage flows | . surface diversions<br>. precipitation<br>. subsurface sources<br>. surface drainage sources | . precipitation<br>. trans-basin diversions<br>. groundwater inflow<br>. river inflow into basin |
| **Storage change** | | |
| . soil moisture change in active root zone | . soil moisture change<br>. reservoir storage change<br>. groundwater storage change | . soil moisture change<br>. reservoir storage change<br>. groundwater storage change |
| **Process depletion** | | |
| . crop transpiration[a] | . crop transpiration | . crop transpiration<br>. municipal and industrial use<br>. fisheries, forestry, and other non-crop depletion<br>. dedicated environmental wetlands |
| **Non-process depletion** | | |
| . evaporation from soil surface, including fallow lands<br>. weed evapotranspiration<br>. lateral or vertical flow to salt sinks<br>. flow to sinks (saline groundwater, seas, oceans)<br>. water rendered unusable due to degradation of quality | . evaporation from free water and soil surfaces, weeds, phreatophytes, and other non-crop plants<br>. flow to sinks (saline groundwater, seas, oceans<br>. evaporation from ponds/playas<br>. water rendered unusable due to degradation of quality | . evaporation from free water and soil surfaces, weeds, phreatophytes, and other non-crop plants<br>. flow to sinks (saline groundwater, seas, oceans<br>. evaporation from ponds/playas<br>. water rendered unusable due to degradation of quality<br>. evapotranspiration from natural vegetation |
| **Outflow** | | |
| . deep percolation<br>. seepage<br>. surface runoff | . instream commitments such as environment and fisheries<br>. downstream commitments<br>. for M&I use within irrigation service<br>. uncommitted outflows | . instream commitments such as environment and fisheries<br>. downstream commitments<br>. outflow commitments to maintain environment<br>. uncommitted outflows |

[a]Crop evapotranspiration may be considered process depletion when it is impractical to separate evaporation and transpiration components, or when separation of terms does not add to the analysis.

Note: M&I = Municipal and industrial uses

## 2.5 Water Quality

Good–quality water is a valuable resource which should be used wisely (Deb and Asce, 1996). Water conservation is not only the careful and wise use of water, but also the prevention of deterioration in the quality of use.

### 2.5.1 Water Quality Indicators

Water quality can be expressed in terms of the physical and chemical composition of the water, and also in terms of its effect on instream biota (MWRC, 1995). The physical characteristics of water include temperature, colour, turbidity, suspended solids, and taste and odour. On the other hand, chemical characteristics include inorganic minerals, pH and alkalinity, acidity, biological oxygen demand, chemical oxygen demand, and dissolved gases. The physical characteristic are outlined below (Malina, 1996).

The temperature of water affects some of its important physical properties and characteristics, such as density, specific weight, salinity, solubility of dissolved gases, etc.

Colour in water is primarily a concern of water quality for aesthetic reasons. Coloured water gives the appearance of being unfit to drink, even though the water may be perfectly safe for public use. On the other hand, colour can indicate the presence of organic substances, such as algae or humic compounds.

Turbidity is a measure of the light-transmitting properties of water and is comprised of suspended and colloidal material. Turbidity is important for aesthetic and health reasons, and is associated with microorganisms.

Suspended Solids may be of inorganic particles such as clay, silt, and other soil constituents; or they may be of organic origin such as plant fibres, or biological solids like algae, bacteria, etc. These are solids which can be filtered out by a fine filter paper. Water high in suspended solids may be aesthetically unsatisfactory for purposes such as bathing as the suspended solids provide adsorption sites for chemical and biological agents (Rowe and Abdel-Magid, 1995).

Biochemical oxygen demand (BOD), the most widely–used chemical parameter, is a measure of the demand for dissolved oxygen by organisms which break down organic matter in water. It is therefore an indirect measurement of the concentration of organic matter in the water. The 5-day BOD ($BOD_5$) is most widely used. On the other hand, nutrients such as nitrate and phosphate are essential for the growth of plants and other organisms. Nutrient levels in water strongly influence the growth of those organisms which, in large quantities, become undesirable.

Instream invertebrates can be used to assess water quality in rivers and streams because some groups of invertebrates are more tolerant of polluted water than others. They are primarily larvae of insects, such as stoneflies, mayflies, and caddisflies, which live among stones on the bottom of rivers. The Macroinvertebrate Community Index (MCI) quantifies the presence or absence of invertebrates, which are ranked according to their sensitivity to organic enrichment, therefore indicating levels of water quality. Rivers with an MCI value of less than 80 are defined as "grossly polluted" (MWRC, 1995). Direct biological assessments of the health of biotic communities in receiving waters offer several important advantages over chemical-based approaches. For example, organisms integrate environmental conditions over time, whereas chemical data are instantaneous in nature and require large number of measurements for an accurate assessment (De Pauw and Vanhooren, 1983) as cited by Metcalfe-Smith (1996).

#### 2.5.1.1 New Zealand Water Quality Standards

Heatley (1996) as cited by Forsyth (1996) prepared a summary of regional council and authority requirements for discharges of dairyshed and piggery wastewater. The table below shows the "receiving water" water quality requirements for the Manawatu-Wanganui Region. All receiving water limits apply after reasonable mixing. The length of river or water body which will be allowed for reasonable mixing will be stated on the discharge permit.

**Table 2.2 Manawatu-Wanganui Region Requirements for Discharges to Water (Source: Forsyth, 1996)**

| Parameter | Standard |
|---|---|
| $BOD_5$ ($g/m^3$) | ≤ 2 (dissolved carbonaceous) |
| Suspended solids ($g/m^3$) | ≤ 5 (particulate organic matter) |
| Ammonia ($g/m^3$) | < 1.1 at temperatures ≤15$^0$C<br>< 0.8 at temperatures > 15$^0$C |
| Phosphorus ($g/m^3$) | ≤ 0.015<br>≤ 15 $mg/m^3$ (dissolved reactive phosphorus) in the Manawatu catchment |
| Change in horizontal visibility | ≤ 30% |
| Change in hue | ≤ 10 Munsell points |
| Change in euphotic depth | ≤ 20% |

## 2.6 Conclusions

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

- Aside from surface and groundwater data, specific data on water use are needed in any basin-resources assessment to determine the adequacy of existing water supplies and to compare the supplies with perceived needs. These data on water use are needed also to judge how uses within the basin affect the availability of water for other purposes.

- While "efficiency" as a measure of water use has restricted application to water allocation and management measures, it is essential to have a thorough understanding of the term–its value for various categories of use within the consumptive class of use and its value at different levels in the hydrologic cycle. At the basin level, investment decisions need to be based on more comprehensive views of basin water use when considering whether a certain level of local efficiency is appropriate, or should be increased. Increasing water use efficiency with conservation measures which reduce the amount of drainage from a particular use in a closed water basin results in "dry" water savings. In open systems on the other hand, reducing this loss by reducing drainage water results in "wet" water savings, a real gain in efficiency.

- While methods such as streamflow records to establish historical maximum and minimum flows, using the initial records of groundwater levels and basic aquifer tests to determine the percentage of the resource to be recovered, are useful in analysing a basin's water resource potential, development upstream may disturb the river's flow to a point where these traditional methods are inadequate.

- The water balance approach, while it has some limitations, can be quite useful–and has been successfully used to study water use and productivity at basin, irrigation and field level (Owen-Joyce and Raymond, 1996; Roberts and Roberts, 1992; Mishra et al., 1995). In addition, the use of models in water balance studies to simulate hydrological processes has enhanced knowledge about and predictability of, water resources.

- The water accounting approach classifies water balance components into water use categories which reflect the consequences of human interventions in the hydrologic cycle–hence its use as an assessment method would give a better understanding of what is happening in a water resource. It is an accounting procedure, which could determine the status of, and measure the changes in, the sustainable output per unit of water effectively depleted.

# CHAPTER III

# THE OROUA CATCHMENT

## 3.1 Introduction

This chapter contains the description (geography and land use) and values associated with the catchment. It also describes the surface and underground water demands and abstractions, and the significant issues resulting from these activities. This information were derived mainly from the Oroua Catchment Water Allocation and River Flows Regional Plan (MWRC, 1997).

## 3.2 Catchment Description

The Oroua River, which rises in the Ruahine Ranges east of Rangiwahia, has its headwaters in rugged country in the Ruahine State Forest Park, with main ridges having an altitude of over one thousand six hundred meters. The Oroua Catchment–which is shown at figure 3.1, has a total area of approximately 900 square kilometres. Much of the catchment water yield comes from its mountainous watershed. While the Park covers only some 10% of the catchment, it is important to the area as a whole because some 80% of low flows in the river have been estimated to come from this small area. During low flow periods, tributary flow is extremely limited. This is especially so in areas 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.

The Oroua River flows through a fairly narrow catchment comprising steep to rolling countryside below the Ruahine State Forest Park, then passes through a series of old river terraces before flowing into the Manawatu River near Rangiotu. The western side of the lower catchment, south of Rongotea, is serviced by an extensive drainage scheme that discharges water to the Oroua

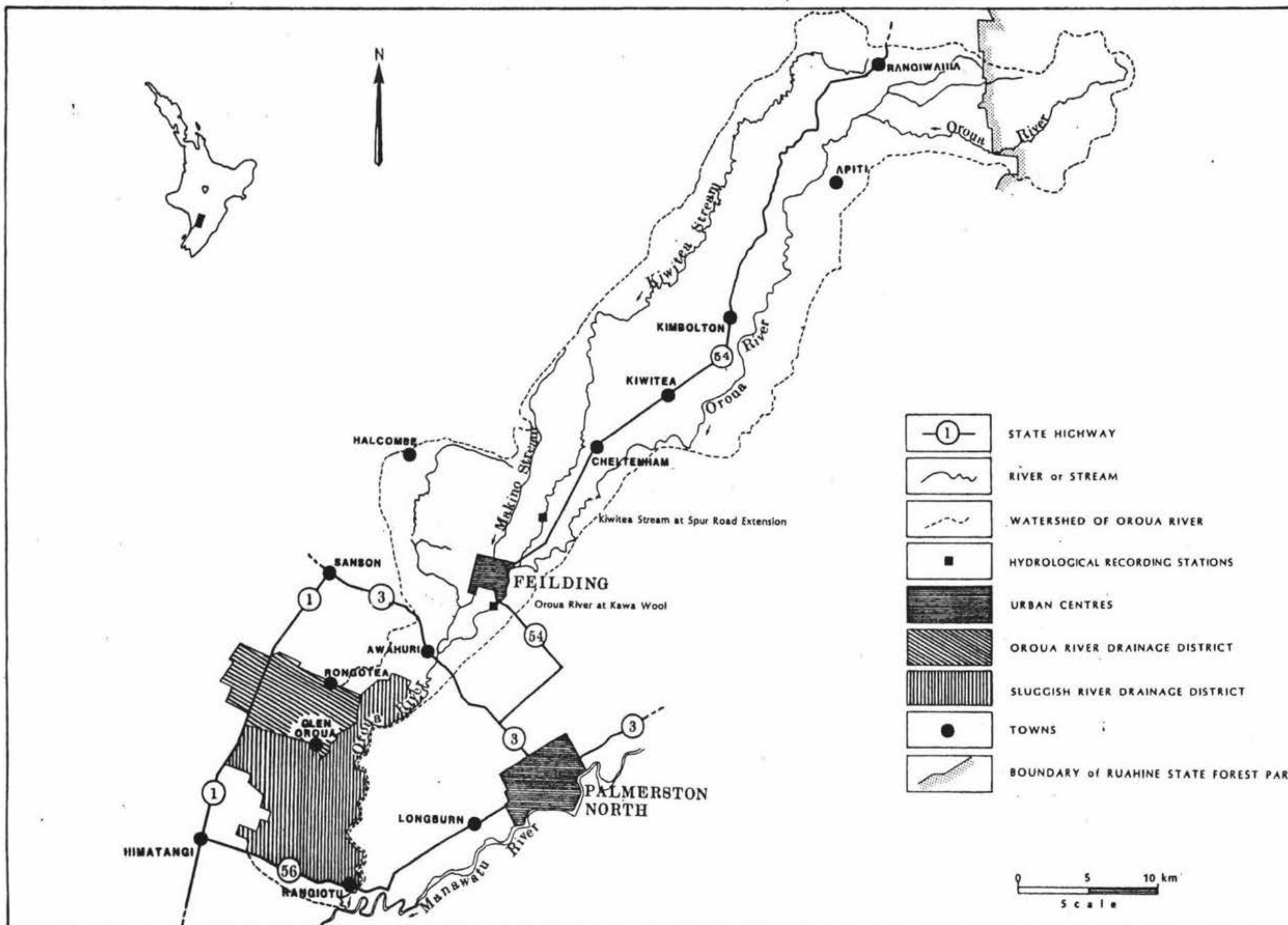



**Figure 3.1 Map of the Oroua River Catchment (Source: MWRC)**

River through floodgates. The major tributaries of the Oroua River are the Mangoira, Miangaroa, Kiwitea and Makino Streams.

Feilding (population 12,000), is the largest urban settlement in the catchment. More than 5,000 people live in a number of smaller rural settlements which service the intensive agricultural activities of the catchment. These towns include Rangiwahia, Apiti, Kimbolton, Kiwitea, Cheltenham, Awahuri, Rongotea, Glen Oroua and Rangiotu.

Land use in the catchment is predominantly agricultural. There are about 100 dairy farms, located mostly in the lower part of the catchment. The upper and central portions of the catchment support many sheep farms. Potato is an important crop grown in the area; other crops include cereal, maize, peas, and carrots.

### 3.3 Values Associated with the Catchment

Rivers have a variety of associated values. These include instream values such as fisheries and recreation, amenity and natural values, cultural and spiritual values. All are potentially affected by aquatic habitat quality.

Ngati Kauwhata are tangata whenua within the Oroua catchment area, who have mana whenua interests over the resources in the catchment. There are two marae in the area, the Kauwhata Marae and the Aorangi Marae. Activities which result in the degradation of aquatic habitat and decline of fisheries are generally incompatible with the cultural and spiritual values of the tangata whenua.

The Oroua River was one of the rivers included in the "100 rivers" survey undertaken by the former Fisheries Research Division of the Ministry of Agriculture and Fisheries in 1990. The instream habitat in the Oroua River was surveyed north of Feilding where, at mean annual flow, the velocity and shallow depths are suitable for benthic invertebrates, but the lack of deep water limits the amount of brown trout habitat. The predominance of fine substrate limits both benthic invertebrates and brown trout. Consequently the instream habitat quality of the Oroua River in this reach does not rate very highly when compared to other rivers studied in New Zealand. Conditions in other sections of the river are, however, different–particularly upstream where the gradient is steeper and the substrate coarser. With good riparian vegetation, such conditions are likely to provide good trout habitat with the existing flow regime. Further studies of the instream habitat in the upper reaches of the Oroua catchment would be needed to assess their value to trout and other aquatic fauna.

There is high recreational use of the upper portion of the catchment in the Ruahine State Forest Park by trampers and hunters. The Park contains regenerating forest with pockets of heavy podocarp in the river valley, red beech on the mountain ridges and sub-alpine forest on the upper ridges. It is the least–altered area of the catchment. The Mangoira tributary, which rises in the Park, flows through a scenic river valley before joining the Oroua River east of Mangarimu. Some small tributaries of the Mangoira and the Kiwitea Streams have their source in the Rangiwahia Scenic Reserve, and the Apiti Scenic Reserve is situated adjacent to the Oroua River, just upstream of the Mangoira confluence. Most of this area has high landscape value, and many of the tributaries to the Oroua in this part of the catchment are used for swimming and fishing. Much of the Oroua catchment upstream of Apiti is, therefore, considered to have good recreational and amenity values which are worth maintaining.

The Oroua catchment contains self-sustaining stocks of brown trout. Canoeing in the Oroua River is possible and may increase in popularity. Access points to the river near Feilding provide popular visiting sites for recreational users, with picnicking areas valued for their safety and proximity to Feilding and Palmerston North.

### 3.4 Groundwater

Groundwater resources in the Oroua Catchment are limited and, in most areas, cannot be used as an alternative to surface water. There is little scope for using shallow groundwater resources in the catchment because the water is sometimes contaminated with iron and manganese making it unsuitable for uses such as water supply. In the Feilding area, high quality groundwater is found in aquifers at least 60 metres deep. Wells that tap aquifers at this depth are expensive to drill. In some areas of the catchment there is no deep aquifer resource available for exploitation. The geology of the catchment above Feilding enables surface water flow to enter the groundwater system; using this groundwater is, therefore, likely to affect surface water flow.

### 3.5 Surface Water Demands

There is high demand to abstract water from the Oroua catchment. This has to be met from surface water resources because of the poor water quality and inadequacy of groundwater resources. User groups include those taking for stock and domestic use, town and rural water supplies, crop and pasture irrigation and industrial use. Most surface water abstraction is concentrated in the middle reaches of the catchment between Almadale and Awahuri.

In addition to high demands on the surface water for water supply, the Oroua River is used also to assimilate up to 8640m$^3$/day of treated waste from the sewage treatment plant at Feilding. This plant handles a large quantity of trade waste from its urban-based industries, so waste discharged from the plant fluctuates according to seasonal processing.

## 3.6 Issues

### 3.6.1 Adverse effects on river and stream environments caused by low flows in rivers during summer dry periods

During most of the year water abstractions from the Oroua catchment have no adverse impact on the river environment. Flows are sufficiently high to withstand some decrease without any adverse effects. Also, during the winter months, there is rarely any need for abstraction for irrigation. However, human–induced low flows occur in the Oroua River and the Kiwitea Stream during summer months. Adverse effects include reduction in the area of habitat available to aquatic life, changes in the nature of the stream (variations in the combination of pools and riffles), changes in the substrate, changes in competition or predation opportunities, and availability of cover, decreases in flow velocity or flow depth, and increases in water temperature with resultant decreases in the concentration of dissolved oxygen in the water.

### 3.6.2 Unacceptable water quality in the Oroua River downstream of Feilding at times of low flow

Adverse effects on water quality are caused by a number of activities. These include large "point source" discharges to waterways in the catchment, cumulative effects of incremental low impact point source discharges, and non-point source pollution (for example, rural runoff). Water enriched by effluent discharges encourages undesirable biological growths such as sewage fungus and filamentous algae. The growth rate of bacteria and/or fungi which can form sewage fungus changes with the season and the state of the river flow. Slower growth in the winter is also caused by physical factors (lower temperatures or scouring by floods). Water quality data for the Oroua catchment indicates that, above major point sources in the rivers, nitrate concentrations are higher during winter than during summer, particularly at times of increased flows. This indicates that rural runoff causes greater effect on water quality in times of high flow than at times of low flow. Point source discharges to the Oroua River cause serious water quality degradation at times of summer low flow (when there are also more light and higher temperatures); rural runoff probably has minimal effect at these times.

Water quality degradation from large point source discharges at Feilding presents a serious threat to instream uses of the river, and compromises the ability of communities to take advantage of the water resource. Some discharges are inconsistent with Maori cultural values, and compromise recreational use of the river.

### 3.6.3 Management of competing demands for surface water resources

There are currently 21 abstractions by 17 permit holders who may take up to a total of 40,000 cubic metres of surface water from the Oroua catchment per day. The other competing demand, particularly for water in the Oroua River at Feilding, is for the assimilation of effluent

At present, the management of the river is being governed by two management plans: the Oroua River Catchment Water Allocation and River Flows Regional Plan, and the Manawatu Catchment Water Quality Regional Plan. The Oroua Catchment Water Allocation and River Flows Regional Plan provides for the management of adverse environmental effects caused by low flows in the Oroua River catchment. It builds upon an existing agreement between the Manawatu-Wanganui Regional Council and major water permit holders to limit abstractions at times of low flow, and provides the methods necessary to apportion, restrict or suspend water abstractions in a way that is predictable and equitable, when flows in the Oroua River and Kiwitea Stream reach thresholds which threaten the river environment.

On, the other hand, The Manawatu-Wanganui Catchment Water Quality Regional Plan addresses the adverse environmental effects caused by the degradation of water quality in the Manawatu River catchment, of which the Oroua is a sub-catchment.

# CHAPTER IV

# METHODOLOGY

## 3.1 Introduction

The newly–introduced Water Accounting Methodology of water resource assessment was tried in the Oroua River Catchment to document the water uses in the study area, and to assess the water availability in relation to the different uses. The assessment was composed of 3 analyses. First, the methodology was tried in a basin-wide assessment (Chapter V). When the first trial failed due to limited data, a second trial was performed by considering only the streams (Chapter VI). The third was the analysis without the Feilding sewage discharge (Chapter VII). This chapter presents a detailed explanation of the methodology applied in the computation of the different components of the water accounting such as: inflow, storage change, process and non-process depletion, and outflow.

The information used in the calculation of the water balance of the catchment was obtained from the following sources: the Manawatu-Wanganui Regional Council (MWRC), National Institute of Water and Atmospheric Research (NIWA), and the holders of water resource consents. Point rainfall and evaporation data were obtained from NIWA, while information on industrial and urban withdrawals, water quality data of water discharges to the river system were provided by the MWRC. Data on irrigated areas, domestic and stockwater abstractions were derived from water resource consents.

According to Seckler (1996), estimates and projections of average water demand and supply conditions should be made in terms of the minimum dry season supply–not, as is usually the case–in terms of annual averages. Hence, the analyses covered the period of April 1997 to March 1998, the driest period during the last ten years (NIWA). This was the year in which the drought caused by the El Niño phenomenon affected most parts of the country.

## 3.2 Calculation of the Different Water Accounting Components

1. *Net Inflow:* This is the total amount of water flowing into the basin (Gross Inflow) plus or minus the change in storage. It consisted of the precipitation and the change in soil moisture storage. When the precipitation was greater than the potential evapotranspiration (PET) of the month, the change in soil moisture storage was considered as inflow and was added to the Gross Inflow. On the other hand, soil moisture storage change was considered as outflow, and was subtracted from precipitation during months when the PET was greater than the precipitation.

1.1 *Precipitation:* Point rainfall data recorded in meteorological recording stations within the catchment and surrounding areas were converted to areal precipitation using the Theissen method. This method involved plotting the location of the rain gauges on a map of the watershed. Straight lines were drawn between the rain gages, and perpendicular bisectors were then constructed on these connecting lines in such a way that the bisectors enclosed areas of the catchment in the form of a polygon. Since all points within one polygon are closer to its rain gage than to any of the others, the rain recorded was considered to represent the precipitation within the appropriate polygon area. The average precipitation over the watershed was determined by using the equation:

$$P = (A_1P_1 + A_2P_2 + \ldots + A_nP_n)/A$$

Where:

$P$ = average depth of rainfall in the watershed

$A$ = Watershed area

$P_1$, $P_2$, $P_n$ = represent the rainfall depth in the polygon having areas $A_1$, $A_2$,..... $A_n$ within the watershed.

2. *Soil Moisture Storage Change:* Monthly storage change was computed using a monthly climatic water-balance (Wall, 1997). In months when

precipitation was less than the potential evapotranspiration, the soil moisture storage change was estimated using the equation:

$$\Delta\text{SMS} = \text{SMS}\left[e^{\left(\frac{P-PET}{SMS_C}\right)} - 1\right]$$

Where:

$\Delta$SMS = the change in soil moisture storage over one month

SMS = the soil moisture storage at the beginning of the month.

$SMS_C$ = soil moisture storage capacity of the soil

P = precipitation

PET = potential evapotranspiration

During the wet season, when precipitation was greater than the potential evapotranspiration, soil moisture storage change was calculated from:

$$\Delta\text{SMS} = \text{P} - \text{PET}$$

3. *Process Depletion:*

3.1 *Evapotranspiration:* Actual evapotranspiration was estimated for the different land uses in the catchment, and classified into process and non-process depletion. Evapotranspiration from the cultivated areas and pasture were classified as process depletion, while evapotranspiration from the forested area was considered non-process depletion. Actual evapotranspiration was determined by first converting the pan evaporation data recorded for the catchment into potential evapotranspiration using the equation:

$$\text{PET} = K_p \times E_{pan}$$

Where:

PET = potential evapotranspiration

$K_p$ = conversion factor

$E_{pan}$ = pan evaporation

Actual evapotranspiration AET was then calculated for wet months from:

$$AET = PET$$

And for dry months from:

$$AET = P - \Delta SMC$$

3.2 *Municipal and industrial Uses:* Data on these components were obtained directly from the MWRC. These include municipal use and other major abstractions.

4. *Non Process Depletion*

4.1 *Evaporation from Free Water Surface:* This amount was calculated by multiplying the surface water evaporation by the free water surface area. As suggested by the New Zealand Meteorological Service (1986), a reduction factor of 0.73 (for stainless steel tanks) was used to convert the pan evaporation into surface water evaporation. Open-water surface area was estimated by using the length and average width of the tributary streams and the Oroua River.

4.2 *Water Rendered Unusable due to Degradation of Quality:* The amount of water lost to pollution was estimated using the method proposed by Keller and Keller (1995). The physical amount of water lost to pollution from the discharge of effluents was measured by the amount of upstream water which would be required to dilute it back down to the maximum allowed concentration of pollutants. The amount of water needed for the dilution of nutrients ($V_u$) was computed using the relation:

$$C_u V_u + C_e V_e = C_m (V_u + V_e)$$

Where:

$C_u$ = concentration of nutrients upstream of discharge point

$V_u$ = volume of upstream water needed to dilute the effluents down to the maximum allowed nutrient concentration.

$C_e$ = concentration of nutrient in the effluent

$V_e$ = volume of effluent discharged into the river

$C_m$ = maximum allowed nutrient concentration

5. *Outflow*

5.1 *Total Outflow:* This component was computed as the difference of the net inflow less total depletion.

5.2 *Committed water:* This is the part of total outflow committed for other uses. The only committed water component used in the study is the instream commitment for environmental maintenance as prescribed in the Oroua Catchment Water Allocation and River Flows Regional Plan. This commitment is the effective minimum flow adopted by the Manawatu-Wanganui Regional Council for the Oroua River to protect the river's life-supporting capacity and to maintain recreational and amenity values associated with that river.

5.3 *Available Water:* This component represents the amount of water available for use in the basin and was computed as the net inflow less committed water.

6. *Indicators*

6.1 *Depleted Fraction:* This is that part of either the net inflow or the available water which was depleted by both process and non-process uses. It was computed from:

$$DF_{net} = \frac{TD}{NI}$$

$$DF_{available} = \frac{TD}{AW}$$

Where:

$DF_{net}$ = depleted fraction of net inflow

$DF_{available}$ = depleted fraction of available water

TD = total depletion

NI = net inflow

AW = available water

6.2 *Process Fraction:* Process fraction relates process depletion to either total depletion or the amount of available water and is represented by:

$$PF_{depleted} = \frac{PD}{TD}$$

$$PF_{available} = \frac{PD}{AW}$$

Where:

$PF_{depleted}$ = process fraction of depleted water

$PF_{available}$ = process fraction of available water

PD = process depletion

TD = total depletion

AW = available water

# CHAPTER V

# BASIN-WIDE WATER ACCOUNTING

## 5.1 Introduction

This chapter presents the different water balance components and the results of the basin-wide water accounting.

## 5.2 Results

### 5.2.1 Water Balance Components

#### 5.2.1.1 Precipitation

The total monthly rainfalls from six stations used in the water budget are shown in Table 5.1. The table shows that the lower part of the catchment received a lesser rainfall as recorded at Bainesse, Waitatapia and Feilding with an annual total of 738.5, 807.5 and 952mm respectively. The upper part of the catchment recorded a higher precipitation with a total of 1122mm in Cheltenham and 1414mm at Apiti. While there is no existing rainfall gauging station in the State Forest Park, an old rainfall map of the catchment showed the rainfall in the Ruahine Range to be much higher than in the rest of the catchment. Since there is no existing rainfall gauging station in the State Forest Park, the rainfall data at Delaware Ridge, a station located at the Ruahine Range south of the State Forest Park (with similar elevation) was selected to represent the forested area.

In estimating the mean catchment precipitation, the catchment was divided into two subcatchments: the State Forest Park–comprising an estimated area of 90km$^2$, and the area below it. The mean precipitation of the area below the State Forest Park was calculated using the Theissen method. The State Forest Park was segregated because the rainfall over this area was too large, thus, including the forest precipitation would have made the mean precipitation large enough to "mask" the deficit in most part of the catchment. A separate water budget then was performed for the State Forest Park.

**Table 5.1 Monthly Precipitation in the Oroua Catchment**

| STATION | Area Covered ($km^2$) | Jan (mm) | Feb (mm) | March (mm) | April (mm) | May (mm) | June (mm) | July (mm) | Aug (mm) | Sep (mm) | Oct (mm) | Nov (mm) | Dec (mm) | Total (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Apiti | 287 | 39 | 68 | 91 | 132 | 39 | 124 | 71 | 112 | 120 | 129 | 108 | 94 | 1414 |
| Cheltenham | 213 | 46 | 87 | 45 | 106 | 19 | 67 | 37 | 88 | 79 | 128 | 98 | 109 | 1122 |
| Waitatapia | 25 | 71.5 | 69.5 | 89.5 | 108.5 | 25.5 | 61.5 | 37.5 | 60.5 | 34.5 | 93 | 62.5 | 93.5 | 807.5 |
| Bainesse | 112 | 39.1 | 86.2 | 65.9 | 131.5 | 28.4 | 46.9 | 40.2 | 33.7 | 66.7 | 78.6 | 47.1 | 74.2 | 738.5 |
| Feilding | 173 | 47 | 66 | 29 | 120 | 29 | 62 | 36 | 52 | 61 | 103 | 64 | 110 | 952 |
| Average | | 43.56 | 75.1 | 62.1 | 121.8 | 29.7 | 83.2 | 49.3 | 80.5 | 86.6 | 115.1 | 86.1 | 98.6 | 931.7 |
| Delaware Ridge | 90 | 63 | 142 | 80 | 206 | 65 | 231 | 238 | 219 | 171 | 211 | 178 | 148 | 2024 |

### 5.2.1.2 Evaporation and Evapotranspiration

While precipitation data were available from several recording stations within the catchment, evaporation data were not. The only evaporation data available were from Palmerston North, downstream of the catchment. The monthly pan evaporation data were converted into open-water and potential evapotranspiration (Table 5.2) using the conversions presented in the methodology section.

**Table 5.2 Total Monthly Evaporation and Evapotranspiration**

| Month | Pan Evaporation (mm) | Open-Water Evaporation (mm) | Potential Evapotranspiration (mm) |
|---|---|---|---|
| January | 148 | 108.33 | 103.88 |
| February | 118.9 | 86.78 | 83.23 |
| March | 81.8 | 59.71 | 57.26 |
| April | 51.8 | 37.81 | 36.26 |
| May | 38.0 | 27.74 | 26.60 |
| June | 11.10 | 8.10 | 7.77 |
| July | 20.0 | 14.60 | 14.0 |
| August | 37.80 | 27.59 | 26.46 |
| September | 55.40 | 40.44 | 38.78 |
| October | 68.6 | 50.08 | 48.02 |
| November | 117.70 | 85.92 | 82.39 |
| December | 142.0 | 103.66 | 99.40 |

### 5.2.1.3 Municipal and Industrial Use

There are three municipal abstractions in the Oroua River: the Kiwitea Rural Water Supply, the Feilding Water Supply and the Oroua Rural Water Supply (Table 5.3). Based on the list of resource consents, the only major industrial abstractor is the Manawatu Beef Packers Ltd. for use in meat processing, with one abstraction for stockwater.

From the above abstractions, only Feilding Water Supply at the Barrows Road intake had an actual abstraction record. To estimate the amount of withdrawal by the other abstractors, monthly ratios of the actual usage to the allowable withdrawal as specified in the resource consent was determined for the Feilding Water Supply. Assuming that the other abstractors used the same percentage of their allowable abstraction, these ratios were multiplied to the volume of water allowed in their resource consents. The estimated monthly Municipal and Industrial abstractions (Table 5.3) was highest during the months of January and December with 527,999 and 507,548m$^3$ respectively. The month of March registered the least with an abstraction of only 313,034m$^3$.

**Table 5.3 Municipal and Industrial Abstraction in the Oroua Catchment**

| | Feilding Water Supply (m$^3$) | Kiwitea Rural Water Supply (m$^3$) | Oroua Rural water Supply (m$^3$) | Waituna West Water Supply (m$^3$) | Manawatu Beef Packers (m$^3$) | Te Hekenga (m$^3$) | Total (m$^3$) |
|---|---|---|---|---|---|---|---|
| January | 244709 | 70476 | 26102 | 21154 | 185408 | 1302 | 549151 |
| February | 216224 | 62273 | 23064 | 18691 | 163826 | 1302 | 485379 |
| March | 207637 | 59799 | 22148 | 17949 | 22148 | 1302 | 330983 |
| April | 205007 | 59042 | 21867 | 17722 | 155327 | 1302 | 460267 |
| May | 211005 | 60769 | 22507 | 18240 | 159872 | 1302 | 473695 |
| June | 188121 | 54179 | 20066 | 16262 | 142533 | 1302 | 422463 |
| July | 214536 | 61786 | 22883 | 18545 | 162547 | 1302 | 481600 |
| August | 213673 | 61538 | 22792 | 18471 | 161893 | 1302 | 479669 |
| September | 213611 | 61520 | 22785 | 18466 | 161846 | 1302 | 479530 |
| October | 215093 | 61947 | 22943 | 18594 | 162969 | 1302 | 482848 |
| November | 231588 | 66697 | 24703 | 20020 | 175467 | 1302 | 519777 |
| December | 235208 | 67740 | 25089 | 20332 | 178209 | 1302 | 527880 |

#### 5.2.1.4 Water Rendered Unusable Due to Degradation of Quality

The amount of water depleted due to the degradation of quality is presented in Table 5.4. These values were computed from the discharges of the Feilding Sewage Treatment Plant using Equation 3. There were no water quality data for the current period hence; data from 1993 to 1995 monitoring were used in this study. While the discharge limit is 9000m$^3$/day, the daily volume of the Feilding Treatment discharge is highly variable from a minimum of 3667 to a maximum of 12787m$^3$/day (MWRC). A median flow rate of 3667m$^3$/day was used in the computation.

The four parameters for measuring the contaminants are Carbonaceous Biochemical Oxygen Demand (total CBOD), Ammonia-Nitrogen (NH4-N), Suspended Solids (SS), and Dissolved Reactive Phosphorus (DRP). The site above the Feilding Sewage Treatment Plant discharge monitored at Bonness Road represents the background water quality ($C_u$). The computation was based on the minimum CR (contact recreation) classification specified in the Manawatu Catchment Water Quality Plan, the maximum allowed concentrations are as follows:

Total CBOD = 10 g/m$^3$
$NH_4$-N = 0.8 g/m$^3$
Suspended Solids = 5 g/m$^3$
Dissolved Reactive Phosphorus = 15 mg/m$^3$

The computed daily volumes of water needed for dilution of the effluents back to their original quality are 14,201m$^3$; 59,722m$^3$; 86,429m$^3$ and 33,957,686m$^3$ for total CBOD, $NH_4$-N, SS and DRP respectively. These are presented in monthly values in Table 5.4. The most critical parameter to be used in determining the amount of water lost due to quality degradation was the Dissolve Reactive Phosphorus. However, the amount of 'background' (upstream) water required to dilute the downstream water back to its original concentration of Dissolved Reactive Phosphorus was greater than the whole streamflow. Using DRP as the critical parameter would indicate water deficit throughout the year. In addition, the DRP Rule limit of 15 mg/m$^3$ as prescribed in the proposed Manawatu Catchment Water Quality Plan is being appealed by the Palmerston North City Council. On the other hand, the use of CBOD or $NH_4$-N will greatly underestimate the amount of water depleted by quality degradation. Hence, Suspended Solids was used as the critical parameter in the water accounting process.

**Table 5.4 Depleted Water Due To Quality Degradation (m$^3$)**

| Parameter | Carbonaceous Bio-Oxygen Demand | Ammonia-Nitrogen | Suspended Solids | Dissolved Reactive Phosphorus |
|---|---|---|---|---|
| January | 440231 | 1851382 | 2679299 | 1052688266 |
| February | 397628 | 1672216 | 2420012 | 950815208 |
| March | 440321 | 1851382 | 2679299 | 1052688266 |
| April | 426030 | 1791660 | 2592870 | 1018730580 |
| May | 440231 | 1851382 | 2679299 | 1052688266 |
| June | 426030 | 1791660 | 2592870 | 1018730580 |
| July | 440231 | 1851382 | 2679299 | 1052688266 |
| August | 440231 | 1851382 | 2679299 | 1052688266 |
| September | 426030 | 1791660 | 2592870 | 1018730580 |
| October | 440231 | 1851382 | 2679299 | 1052688266 |
| November | 426030 | 1791660 | 2592870 | 1018730580 |
| December | 440231 | 1851382 | 2679299 | 1052688266 |

#### 5.2.1.5 Irrigation Abstraction

There are 16 resource consent holders currently abstracting water for irrigation purposes in the catchment, with a total permitted abstraction of 15,814m$^3$/day (Table 5.5).

In order to estimate the actual evapotranspiration from the irrigated portion of the catchment, actual measurement of irrigated area or a record of actual irrigation abstractions is required. However, the farmers were not able to record their abstractions during this summer. Hence, the allowed irrigation abstractions as specified in their water permits were used to estimate the irrigated area. This method could have overestimated the actual abstractions because in most cases, actual use is less than the limits applied for in the resource consents.

**Table 5.5 Irrigation Abstractions**

| Name of Stream | No of Abstractions | Existing Use ($m^3/d$) | Area Irrigated ($km^2$) |
|---|---|---|---|
| Oroua River | 8 | 10,633 | 3.54 |
| Kiwitea Stream | 4 | 3,061 | 1.02 |
| Makino Stream | 3 | 1,472 | 0.49 |
| Mangaone West Stream | 1 | 648 | 0.22 |
| Total | 16 | 15,814 | 5.27 |

### 5.2.2 Monthly Climatic Water Budget

A simple soil water budget model which uses climatic data was used to determine the actual evapotranspiration and storage change. The two major inputs are the rainfall and evapotranspiration/open-water evaporation presented in tables 5.1 and 5.2. Along with rainfall and evapotranspiration, information on the available water capacity of the soil was required.

Available Water Capacity of the soil is influenced by two factors: the soil type (texture, etc.) and the depth of soil which plant roots explore. According to Molloy (1993), soils in the Manawatu are generally classified as Dense Grey soils, and their textural classification as silt loam. The estimated rooting depth for pasture (silt loam and sandy soils) is 0.4metre (Mcfetridge, 1997) while the rooting depth for the forested area was estimated to be 1metre (Gasson and Cutler, 1990).

Using this information and the water holding capacities (WHC) of the different soil types (NZS5103: 1973), the available water capacity of the pasture and irrigated area were estimated to be 80mm while the forested area was 170mm (refer appendix 3).

The monthly surplus generated from the water budget was distributed by assuming a 40% surface and groundwater detention. In this case, the total runoff for the month was 60% of the total available for runoff (TARO) i.e., 60% of the sum of the month's surplus plus the previous month's detention. The monthly actual evapotranspiration and storage changes were then entered in a summary table to estimate the streamflow from the catchment.

### 5.2.3 Water Accounting

The different water balance components discussed in the previous sections were entered in a summary table (Table 5.6) to assess the adequacy (available water, uncommitted outflow) of water in the catchment, and to determine the different depletion (depleted fraction, process fraction) indicators.

Inflow to the basin was derived entirely from precipitation, there is no river inflow into the basin, and subsurface sources from outside sub–basin was assumed to be zero (table 5.6). Net inflow for each month was computed by adding or subtracting the change in storage to the precipitation for a total of $781 x 10^6$ $m^3$. The total depletion which consisted of process depletion (evapotranspiration and M&I abstractions) and non-process depletion (forest and free water evaporation water lost due to quality degradation) was estimated to be $580 x 10^6$ $m^3$ resulting in an outflow of $200.6 x 10^6$ $m^3$.

During the months of April to December, there was enough water in the catchment to supply the different abstractions. There was also enough water to dilute the effluent discharges and to satisfy the minimum flow (committed outflow) being observed in the Oroua River to protect the life-supporting capacity of the river as indicated by the positive values of uncommitted outflow during these months. The month of October registered the highest outflow, with $59.6 x 10^6$ $m^3$–followed by June with $57 x 10^6$ $m^3$. However, the months of January, February and March registered negative values of uncommitted water (Table 5.6), with $-1.7 x 10^5$, $-1.5 x 10^6$, and $-2.3 x 10^6$ $m^3$ respectively. This means that there was not enough good quality water to satisfy the minimum flow being observed in the river.

Depletion, starting from December to March–especially during February and March is very high–with 99% of the total inflow depleted (depleted fraction). During these months, the basin is considered closed i.e.; most of the inflows were depleted within the catchment. Process depletion which included the evapotranspiration from pastures and cultivated areas and the different M&I abstractions was highest during the month of December with $80.6 \times 10^6\ m^3$, while June registered the lowest with $6.7 \times 10^6\ m^3$. The months of November and December have the highest process fraction of depleted water, both with 0.87. Despite having a higher total depleted fraction, the months of January, February and March registered a lower process fraction. The actual evapotranspiration, which comprised the greater part of the process depletion was limited due to lower soil moisture content resulting from the rainfall deficit during this period.

**Table 5.6. Water Accounts of the Oroua River Basin: April 1997 to March 1998**

| | January | | February | | March | | April | | May | | June | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Component | Total | Component | Total | Component | Total | Component | Total | Component | Total | Component | Total |
| **Gross Inflow** | | 40958700 | | 73636900 | | 57537300 | | 117202500 | | 29925300 | | 90475300 |
| Precipitation | 40958700 | | 73636900 | | 57537300 | | 117202500 | | 29925300 | | 90475300 | |
| **Storage Change** | | 42870523 | | 1201777 | | -2952591 | | -33462625 | | 17916353 | | **-23366591** |
| Soil Moisture Δ | 36854121 | | -397166 | | -3911418 | | -6961571 | | 0 | | 0 | |
| Groundwater Storage Δ | 6016402 | | 1598943 | | 958826 | | -26501054 | | 17916353 | | -23366591 | |
| **Net Inflow** | | **83829223** | | **74838677** | | **54584709** | | **83739875** | | **47841653** | | **67108709** |
| **Process Depletion** | | 69565304 | | 63957518 | | 46482543 | | 29685827 | | 21913295 | | 6685083 |
| Evapotranspiration | 69016153 | | 63472139 | | 46151560 | | 29225560 | | 21439600 | | 6262620 | |
| Municipal & Industrial | 549151 | | 485379 | | 330983 | | 460267 | | 473695 | | 422463 | |
| **Non-Process Depletion** | | 12052883 | 347188 | 10257900 | | 8071555 | | 5206316 | | 4356342 | | 3402282 |
| Free Water Evaporation | 433328 | | 7490700 | | 238856 | | 151256 | | 110960 | | 32412 | |
| Forest Evaporation | 8940256 | | 2420012 | | 5153400 | | 3263400 | | 2394000 | | 777000 | |
| Degraded Water | 2679299 | | | | 2679299 | | 2592870 | | 2679299 | | 2592870 | |
| **Total Depletion** | | **81618187** | | **74215418** | | **54554098** | | **35693353** | | **27097554** | | **10087365** |
| **Total Outflow** | | **2211036** | | **623259** | | **30610** | | **48046522** | | **20744099** | | **57021344** |
| Committed Water | | 2402531 | | 2170028 | | 2402531 | | 2325030 | | 2402531 | | 2325030 |
| Uncommitted Outflow | | -191495 | | -1546769 | | -2371921 | | 45721492 | | 18341568 | | 54696314 |
| Available Water | | 81426692 | | 72668649 | | 52182178 | | 81414845 | | 45439122 | | 64783679 |
| Available for Irrigation | | 80877541 | | 72183270 | | 51851194 | | 80954578 | | 44965427 | | 64361216 |
| **Indicators** | | | | | | | | | | | | |
| DFnet | | 0.97 | | 0.99 | | 0.99 | | 0.43 | | 0.57 | | 0.15 |
| PFdepleted | | 0.85 | | 0.86 | | 0.85 | | 0.83 | | 0.81 | | 0.66 |
| PFavailable | | 0.85 | | 0.88 | | 0.89 | | 0.36 | | 0.48 | | 0.10 |

*The above figures are in cubic meter ($m^3$)

## Table 5.6 Continued

| | July | | August | | September | | October | | November | | December | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Component | Total | Component | Total | Component | Total | Component | Total | Component | Total | Component | Total |
| **Gross Inflow** | | 61345900 | | 84880900 | | 85542900 | | 112224200 | | 85799700 | | 93192900 |
| Precipitation | 61345900 | | 84880900 | | 85542900 | | 112224200 | | 85799700 | | 93192900 | |
| **Storage Change** | | 3789331 | | -3382737 | | 2938526 | | -6192338 | | 20364743 | | 11935577 |
| Soil Moisture Δ | 0 | | 0 | | 0 | | 0 | | 0 | | 630638 | |
| Groundwater Storage Δ | 3789331 | | -3382737 | | 2938526 | | -6192338 | | 20364743 | | 11304938 | |
| **Net Inflow** | | **65135231** | | **81498163** | | **88481426** | | **106031862** | | **106164443** | | **105128477** |
| **Process Depletion** | | 1176600 | | 21806428 | | 31736210 | | 39186967 | | 66926116 | | 80641156 |
| Evapotranspiration | 11284000 | | 21326760 | | 31256680 | | 38704120 | | 66406340 | | 80113275 | |
| Municipal & Industrial | 481600 | | 479668 | | 479529 | | 482847 | | 519776 | | 527880 | |
| **Non-Process Depletion** | | 3997699 | | 5166539 | | 6244838 | | 7201411 | | 10351654 | | 12039939 |
| Free Water Evaporation | 58400 | | 105840 | | 161768 | | 200312 | | 343684 | | 414640 | |
| Forest Evaporation | 1260000 | | 2381400 | | 3490200 | | 4321800 | | 7415100 | | 8946000 | |
| Degraded Water | 2679299 | | 2679299 | | 2592870 | | 2679299 | | 2592870 | | 2679299 | |
| **Total Depletion** | | **15763299** | | **26972967** | | **37981048** | | **46388378** | | **77277770** | | **92681095** |
| **Total Outflow** | | **49371932** | | **54525196** | | **50500378** | | **59643484** | | **28886673** | | **12447382** |
| Committed Water | | 2402531 | | 2402531 | | 2325030 | | 2402531 | | 2325030 | | 2402531 |
| Uncommitted Outflow | | 46969401 | | 52122665 | | 48175348 | | 57240953 | | 26561643 | | 10044851 |
| Available Water | | 62732700 | | 79095632 | | 86156396 | | 103629331 | | 103839413 | | 102725946 |
| Available for Irrigation | | 62251100 | | 78615964 | | 85676866 | | 103146484 | | 103319637 | | 102198065 |
| **Indicators** | | | | | | | | | | | | |
| DFnet | | 0.24 | | 0.33 | | 0.43 | | 0.44 | | 0.73 | | 0.88 |
| PFdepleted | | 0.75 | | 0.81 | | 0.84 | | 0.84 | | 0.866 | | 0.87 |
| PFavailable | | 0.19 | | 0.28 | | 0.37 | | 0.38 | | 0.64 | | 0.78 |

## 5.3 Discussion

The water accounting of the Oroua River for the year 1997-1998 showed a net inflow of 781x10$^6$ m$^3$. The total depletion was estimated to be 580x10$^6$ m$^3$ with an outflow of 201x10$^6$ m$^3$. However, 28x10$^6$ m$^3$ of the outflow was committed for environmental maintenance, to protect the life-supporting capacity of the river. With this estimate for environmental commitment, the remaining uncommitted outflow was 172x10$^6$ m$^3$. The depleted fraction of the net inflow was 0.74 while the process fraction of depleted water and the process fraction of available water were 0.845 and 0.675 respectively.

The uncommitted outflow of 172x10$^6$ m$^3$ (depleted fraction of only 0.74) seemed to indicate enormous excess water which could be tapped for further use. However, water management decisions based on the annual estimates could be misleading because most of the excess water was recorded during the months when abstractions such as irrigation were not in demand. Hence, drawing conclusions from the annual figures will lead to an overestimate of the streamflow–for it overlooks the situation during summer months. This is true since the supply of, and demand for, water vary dramatically season by season. In the wet season, the demand is low and the supply is plentiful. In the dry season, the situation is reversed i.e. there is not enough water in the streams for all requirements. Therefore, water management should also aim at low flows (Brilly et al., 1997). Estimates and projections of average per capita water demand and supply conditions should be made in terms of the minimum dry season supply–not, as is usually the case, in terms of annual averages (Seckler, 1996). To reflect the condition of the catchment during months of low flow, further analyses by monthly accounting were carried out.

To check the results of the water accounting analyses, the estimated streamflow from the upper portion of the catchment (estimated area of 293 km$^2$) was compared with the actual streamflow recorded at Almadale (refer appendix 1). The comparison showed that the streamflow was underestimated in most of the months, with a total difference for the year of 23.4x10$^6$ m$^3$. The rainfall data used for the State Forest Park could have been inadequate i.e., the actual rainfall for the forested area could be much higher than the rainfall data from Delaware Ridge which were used in the computation. Delaware Ridge was actually outside the catchment, but due to the lack of a rainfall gauging station, it was chosen to represent the forested area (for it resembles the average rainfall in the State Forest Park). A check with an old rainfall map (1940-1970) of the catchment showed a very variable rainfall in the forested area. Further, while the assumption of 60% runoff and 40% detention of the monthly surplus worked well in some months, it did not fit for the other months of the year. Attempts to modify the percentage of monthly runoff and detention to fit the actual monthly distribution were not successful. An accurate catchment model is needed to predict the streamflow.

In addition to the above–mentioned discrepancies, it was noted that the use of total monthly streamflows did not correctly reflect the real situation in the river. This is true because the use of total monthly values assumed a uniform flow throughout the month. While it appeared that there was abundant streamflow, it was observed that the greater part of the total monthly flows occurred within short periods and thus are not available for abstractions. A check of the actual daily river flow from hydrographs recorded by the Manawatu–Wanganui Regional Council showed that the monthly total 'masked' the water shortage being experienced in the catchment. Based on the hydrographs, flood events could increase the total flow considerably. Take, for example, the month of February–wherin a flood event at the latter part of the month was able to increase the monthly average streamflow for about $6m^3/s$ (MWRC). The flood, while it lasted for several hours only, increased the total streamflow thereby 'masking' the very low flow occurring prior to the flood event. The flow prior to the flood was as low as 960 l/s, which is below the minimum flow of 1015 l/s maintained at the Almadale Recording Station.

## 5.4 Conclusion

As in any other water balance studies, the water accounting methodology is beset with the problem of estimating the different components such as precipitation and evapotranspiration. Based on the results, the water accounting analyses was not successful in assessing the availability of water in the Oroua River because the monthly water budget failed to produce a reliable estimate of streamflow. The volume of estimated streamflow was greatly underestimated as compared to the actual streamflow recorded at Almadale. However, it could not be concluded that the concept of water accounting did not work. The methodology could be useful for basin-wide water assessment, although the methods of determining the different components still need to be improved because of observed discrepancies between measured and calculated values. To have a better runoff/streamflow estimate, an accurate catchment model is needed.

The major factors which led to the failure of the methodology when used for basin–wide water assessment were doubtful inflow component due to insufficient rainfall data–especially at the State Forest Park (which has no rainfall gauging station), and the soil moisture capacities which were estimated from the crop rooting depths. Insufficient rainfall measurements, especially in mountainous areas where spatial rainfall variability exists, result in inaccurate streamflow estimates (Kostka and Holko, 1993). In addition, the direct measurement of precipitation in the catchment is often replaced by corrections of the lowland precipitation related to elevation (Molnar et al, 1988). This condition is exacerbated by the difficulty in segregating the surplus rainfall into direct runoff and groundwater recharge. The estimate of monthly runoff using a fixed percentage of runoff and detention did not produce a satisfactory streamflow estimate when compared to the actual flow data.

The use of annual estimates is appropriate in arid catchments where precipitation is nil and inflow components are controlled (Molden, 1997). However, in catchments with variable inflow components (i.e. precipitation), the results of the study showed that use of annual and monthly values would tend to lead to overestimation of the available water resource. The use of monthly streamflow estimates could be misleading for they assume a uniform flow throughout the month. In reality, while it appeared that there was enough streamflow, large portions of the total monthly flows occurred within short periods of time and were not available for useful abstraction. The presence of a flood event masked the real situation during low flows.

# CHAPTER VI

# STREAMFLOW WATER ACCOUNTING

## 6.1 Introduction

The first attempt to use the Water Accounting Methodology to determine the extent of water consumption and assess the water availability in the Oroua River catchment was unsuccessful due to unreliable streamflow estimates resulting from inadequate hydrological data. In addition, while the use of a simple climatic model could correctly predict the monthly surpluses, it was very difficult to estimate the distribution of this excess water into direct runoff and recharge. There is a need for a more sophisticated catchment model to produce more accurate streamflow estimates.

Due to the above-mentioned difficulties, it was decided to assess the water availability in the catchment using the measured streamflow of the main streams. The new approach did not cover the entire catchment as originally planned. Instead, it considered only the streams. The new area of the study covered the portion of the Oroua River downstream of the confluence with the Kiwitea Stream (refer figure 3.1). In this case, the results of the analyses represent the situation below the confluence. Measured streamflows from the Oroua River and the Kiwitea stream were used as inflow components. A daily flow record for the Makino Stream was not available for the period 1997-1998, but provisional flow data recorded at Boness Road showed insignificant streamflow during summer months–falling to as low as 80 l/s during the month of February.

In the new approach, the process depletion consisted of only the Municipal and Industrial uses, while non-process depletion included free-water evaporation and water rendered unusable due to degradation of quality. Abstraction for irrigation was not included in the analyses for the following reasons: First, there was no record of actual abstractions–the only available data is from the resource consents. Use of these records would have resulted in an overestimation of the depletion because, during low flow, actual irrigation abstractions were below the amount specified in the resource consents. This is true because restriction on irrigation abstractions take effect when the flow reaches the limit specified in the Oroua Catchment Water Allocation and River Flows Regional Plan. Second, use of the abstraction records would be incorrect since it would assume that all of the diverted irrigation water was depleted. To account for the amount of water which was actually depleted, the depletion from AET must be determined. However, as discussed in the previous chapter, AET is directly affected by precipitation–of which records were inadequate. Since depletion from irrigation was not included, the computed outflow for the summer months did not represent excess water. Instead, it was an estimate of water available for irrigation plus water for environmental maintenance (committed water).

To reflect the real situation during the summer months (when a water shortage existed), the streamflow was analysed using daily flows. The use of daily flows in the analyses showed the day–to–day variations of the streamflow, thereby giving a clearer picture of the river's condition–especially during low flows. In addition, this approach avoided overestimation of the streamflow, as in the case of using monthly values (see previous chapter). The water accounting analyses covered the period from April 1997 to March 1998. The results from May to October were not presented because the daily streamflow records showed that even the minimum flows were enough to satisfy the different abstractions thus indicating no water shortage. Further, water quality is adversely affected not by point sources (i.e. Feilding sewage discharge) but generally by non-point source discharges such as runoff from agricultural lands during this period. Water quality data for the catchment indicates that, above major point sources in the rivers, nitrate are higher during winter than during summer, particularly at times of increased flows (MWRC, 1997). This indicates that rural runoff causes greater effect on water quality during high flows.

## 6.2 Results

### 6.2.1 Total Depletion–$DF_{available}$

The results of the Oroua River water accounting using measured streamflow are shown in Figures 6.1 to 6.6. Presented are the three different water depletion indicators- Depleted Fraction of available water ($DF_{available}$), Process Fraction of depleted water ($PF_{depleted}$), and Process Fraction of available water ($PF_{available}$). The results are from April 1997 and November to March 1998, the period of low flows and the time when peak water demands occur. The streamflows were varied greatly as the streams responded to rainfall events. Generally, the depleted fraction was increasing as streamflow continued to dwindle–the abrupt decrease of $DF_{available}$ represents peak flood events. A fraction with a value of less than 1.0 would indicate sufficient streamflow while values greater than 1.0 would indicate water shortages–the fraction increased with depletions.

In the period under study, sufficient water supply started in the month of April, showing a maximum depleted fraction ($DF_{available}$) of only 0.62 (Figure 6.1) during the first week–the following days showed under 0.2 depleted fraction. There was an abundance of water until the start of the irrigation season in November and December (Figure 6.2 and 6.3). The months of November and December showed a maximum depletion of the available water ($DF_{available}$) of only 0.40 and 0.75 respectively. This shows that further abstraction could have been allowed without adversely affecting water quality. However, the streamflow decreased considerably during the following months. Streamflow started to dwindle in January when depletion began to 'exceed' the available water (Figure 6.4). The following months of February and March showed a severe deficit when, in some instances, depletion was more than thrice the available water (Figures 6.5 and 6.6). This condition of the available water being 'exceeded' was possible because not all of the water was lost in the physical sense. The values of depleted fraction ($DF_{available}$) greater than 1.0 actually indicate the amount of streamflow needed to assimilate pollution from the discharged effluents.

The results showed that the pollution effect due to the Feilding sewage discharge is the biggest streamflow consumer in the Oroua River as shown by the values of $DF_{available}$ much greater than 1.0 (figures 6.4 to 6.6). The indicator's rising beyond 1.0 showed that there was insufficient streamflow to dilute the effluent discharges back into the allowable water quality. It means that the streamflow had fallen too low to be able to assimilate the discharged effluents. Thus, while there was enough water flowing downstream of the Feilding sewage discharge, it was degraded below the water quality standards for contact recreational purposes (Class CR) specified in the Manawatu Catchment Water Quality plan.

### 6.2.2 Process Depletion

While the depleted fraction ($DF_{available}$) of the streamflow was high, process depletions shown by $PF_{depleted}$ and $PF_{available}$ constituted a very small fraction (Figures 6.1 to 6.6). Non-process depletions from free water evaporation and water quality degradation comprised the largest part of the depleted water. This condition was evident throughout the year with all months showing very low process fractions ($PF_{depleted}$ and $PF_{available}$). During the entire summer period, the Process Fraction of depleted water ($PF_{depleted}$) registered a maximum of only 0.19 while the total depletion ($DF_{available}$) was 0.75 on the same day. This means that 0.81 of the depleted water was lost to pollution and evaporation indicating, that the bulk of the streamflow was not beneficially used.

It should be noted, however, that process depletion from irrigation use was not included in the analysis. In this case, the process fraction could be higher with the inclusion of the depletions from evapotranspiration in irrigated areas and other unaccounted abstractions. This would mean that the actual amount of water which was beneficially used was higher than was shown by the indicators. Hence, there was a lesser opportunity for improvement than that which was indicated in the analysis. While the months from April to December showed low process depletion, the larger streamflows during these months were sufficient to assimilate the effluents from the Feilding sewage discharge. On the other hand, the impact of pollution was felt severely in the summer months due to the limited flow.

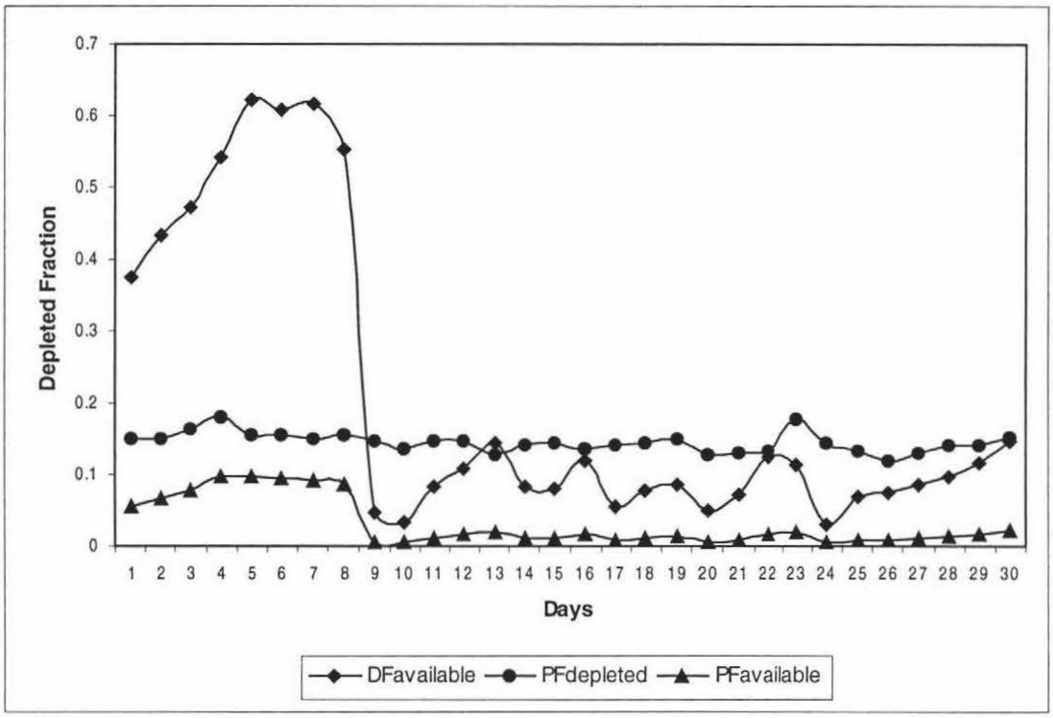



**Figure 6.1 Water Depletion for the Month of April**

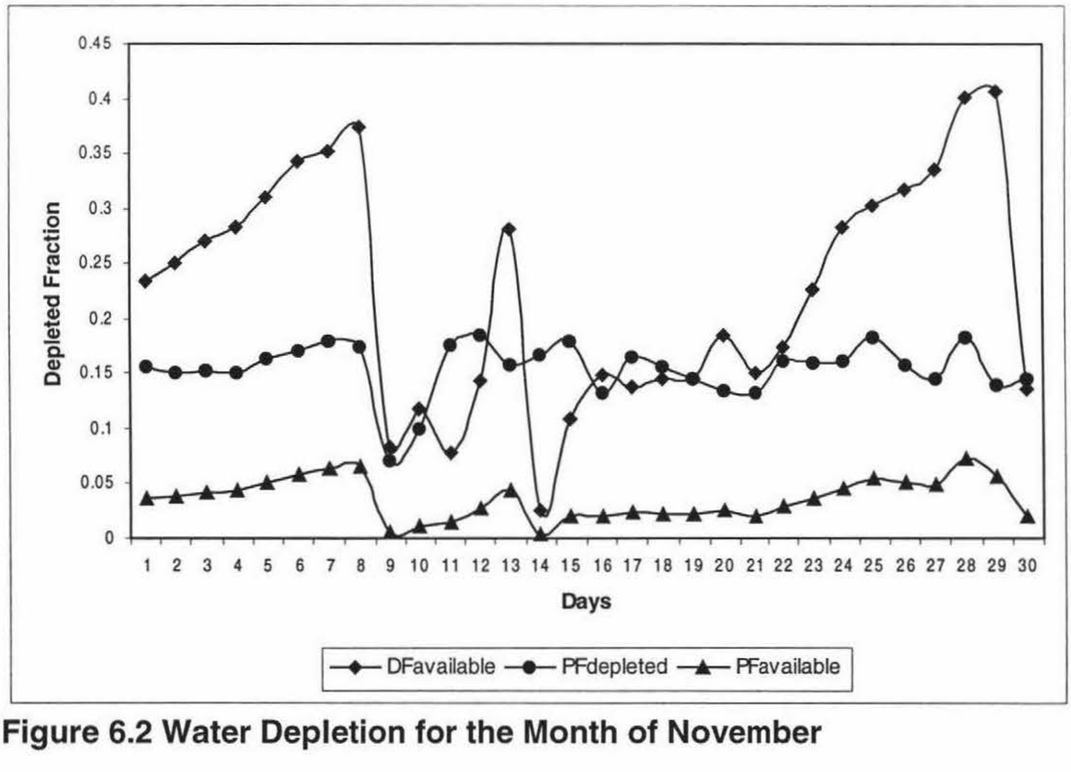



**Figure 6.2 Water Depletion for the Month of November**

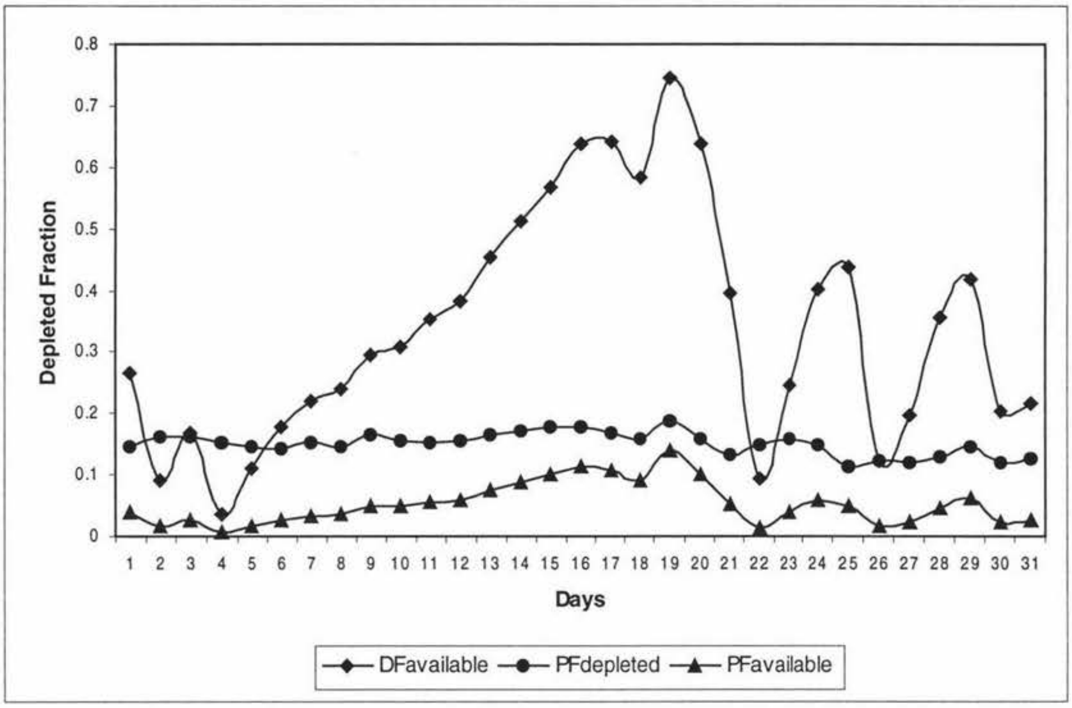



**Figure 6.3 Water Depletion for the Month of December**

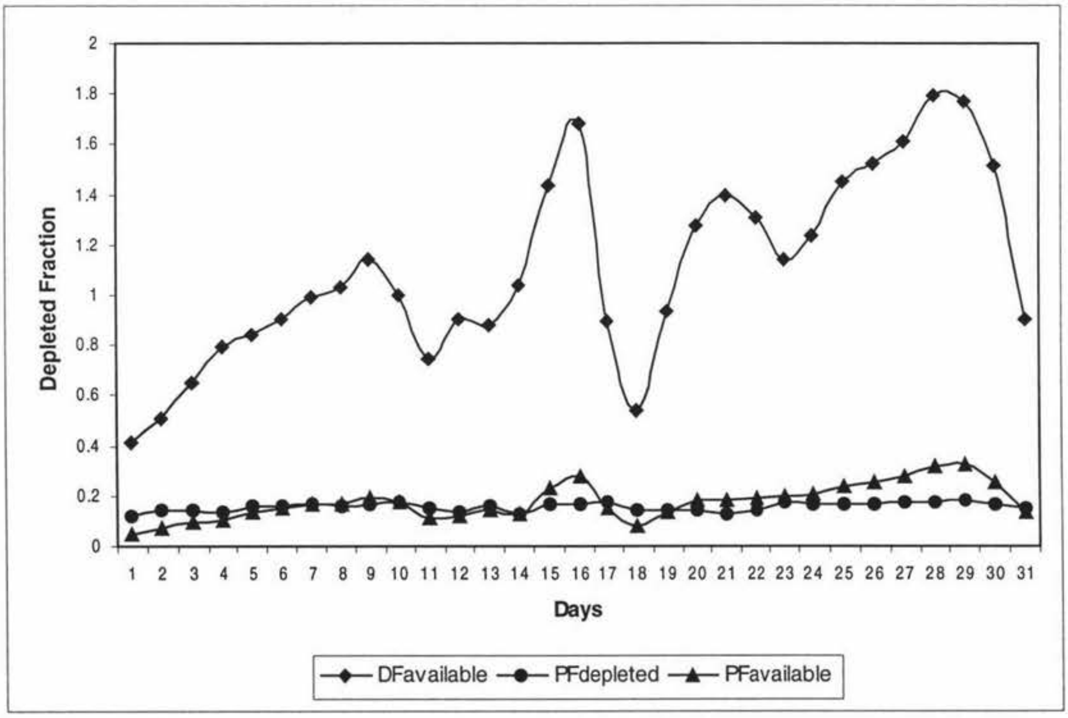



**Figure 6.4 Water Depletion for the Month of January**

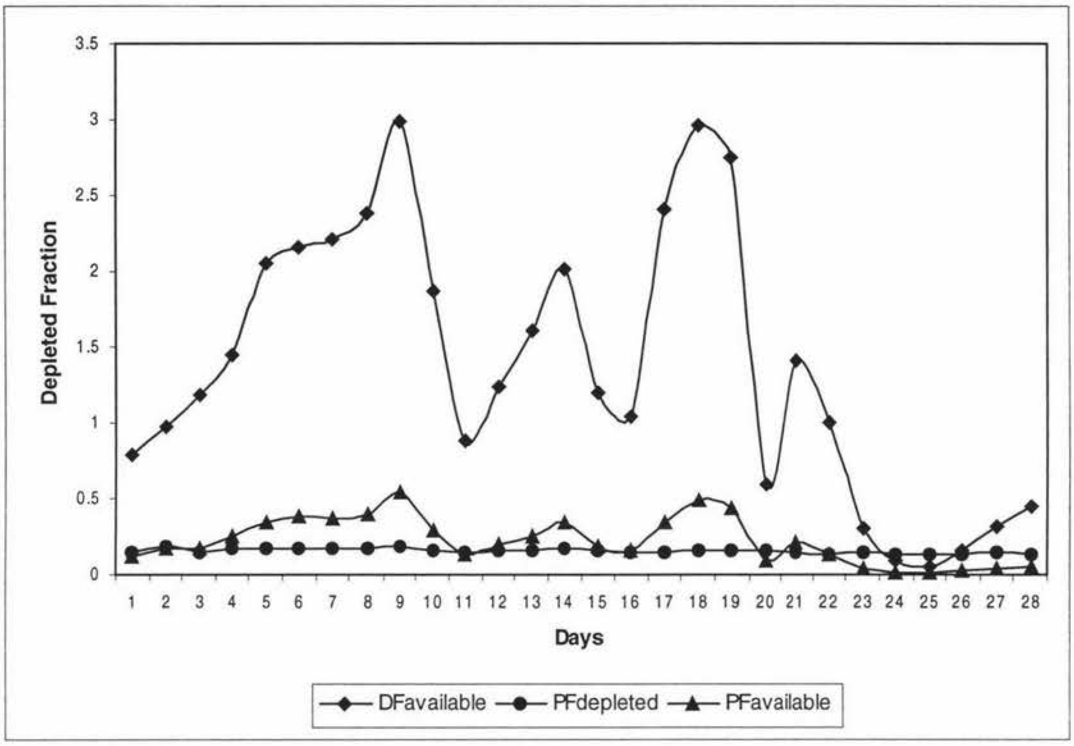



**Figure 6.5 Water Depletion for the Month of February**

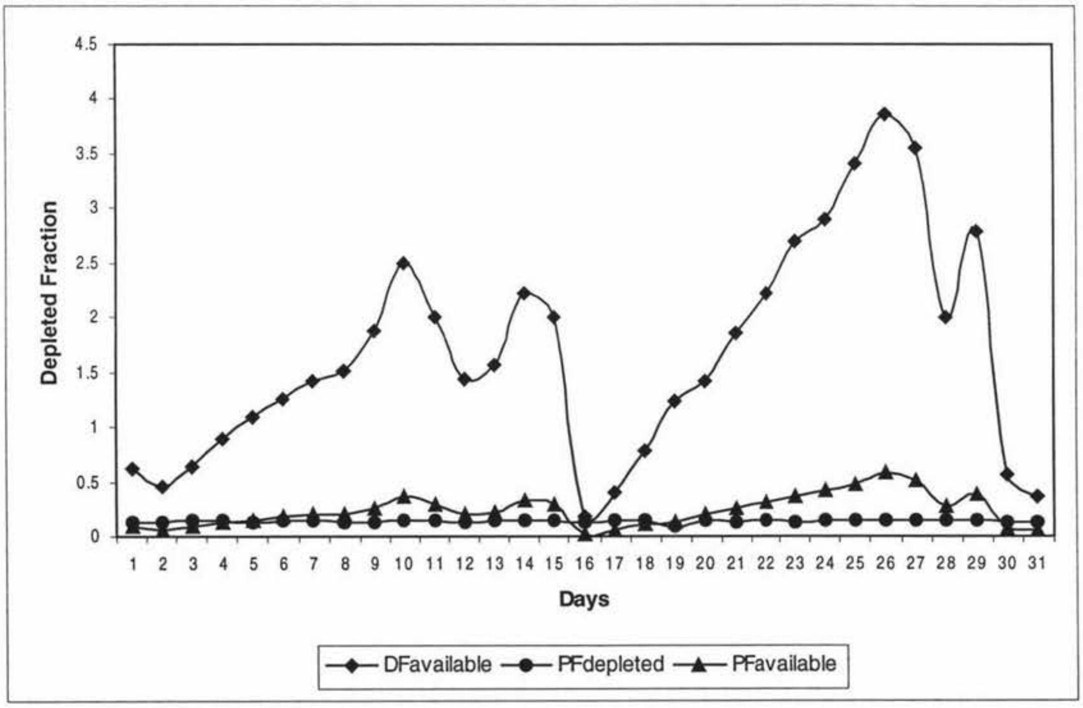



**Figure 6.6 Water Depletion for the Month of March**

## 6.3 Discussion

### 6.3.1 Water Availability in the Oroua River

From April to December, there was sufficient streamflow for the different municipal and industrial abstractions, and for the assimilation of the Feilding sewage discharge. The analyses showed also that, even during the summer months, there was sufficient water for municipal and industrial (M&I) uses as indicated by the low process fractions. This condition represents the situation at the lower part of the catchment i.e., after the confluence of the two streams (Oroua and Kiwitea). The results showed that there was excess water below the confluence with the Kiwitea Stream. However, most of the M&I and the major irrigation abstractions (irrigation abstractions were not included in the analyses) are situated on the Oroua River upstream of the confluence with the Kiwitea Stream. Based on flow hydrographs (refer appendix 1), February and March showed that flow recorded at Almadale reached as low as 1093 and 1022 l/s respectively, the flow at which abstraction for the Feilding Water supply restrictions (specified in the Oroua Catchment Water Allocation and River Flows Regional Plan) come into operation. With abstraction restrictions in effect, it means that all of the available water has been taken for M&I use. Thus, process depletion would be higher at the Oroua River before the Kiwitea Stream confluence.

The overall picture shows that there was a water shortage during the summer period. Although there was sufficient streamflow for M&I use, the flow was not enough to assimilate the sewage discharge–failing to maintain water quality standards set for environmental maintenance. The actual condition could be even more severe than that which was presented in this study if the irrigation abstractions upstream of the Feilding Sewage Discharge–which further decreased the capacity of the stream to assimilate the discharge–were included in the analysis. As presented earlier, there are 16 consent holders currently abstracting water for irrigation purposes, with a total permitted abstraction of approximately 15,814 $m^3$/day (see section 5.2.1.5). Actual figures, however, could be lower since the existing minimum flow plan restricts irrigation during low flows. Based on the results, the 3 summer months from January to March, during which peak water demand occurs, experienced a severe water deficit when, in some instances, depletion 'exceeded' the available water by as much as 3½ times. The bulk of the depletion was due to pollution from the Feilding sewage discharge and those $DF_{available}$ figures exceeding 1.0 represent the times of low flow, when the stream was unable to assimilate the discharged effluents.

The result is consistent with previous studies, which have shown the Feilding sewage discharge markedly affecting the Oroua River. Hooper (1979), who studied the effect of waste discharges on the quality of the river, reported that all the chemical (dissolved oxygen, pH, BOD, COD, suspended solids, total kjeldahl nitrogen, nitrate, and total phosphorus) and microbiological parameters studied, except the nitrate concentrations, were affected by the Feilding waste discharge. The Feilding discharge also brought about a large change in the macroinvertebrate community and, at times, eliminated all macroinvertebrates from the reaches immediately below the discharge. Chan, (1979) who conducted a water quality study on the Oroua River from November 1978 to January 1979, gave a similar observation. Her research showed that the Feilding effluent significantly affected the physico-chemical and microbiological characteristics of the river and that, overall, the Oroua was polluted downstream of the discharge. However, she reported that the river exhibited high dilution and self-purification abilities.

In their assessment of the environmental effects of discharges to the lower Manawatu River, the MWRC (1995) reported that the Feilding discharge would cause Rule limits (specified in the Manawatu Catchment Water Quality Regional Plan) for all five contaminants assessed to be exceeded–largely because of the limited assimilative capacity of the Oroua River. During low river flows, the levels of all contaminants were consistently raised above Rule limits by the discharge. Suspended Solids data from their monitoring programme showed that the 'Background' SS levels at Bonness Road are generally below 5 g/m3 while that at Awahuri Bridge are generally above the Rule limit. Their monitoring showed also a massive increase in Dissolved Reactive Phosphorus between the sites upstream and downstream of the Feilding discharge. Dissolved Reactive Phosphorus levels exceeded the Rule limit by up to 40-fold at the downstream sites, which is consistent with the occurrence of extensive algal growths observed at the Awahuri site during low flows.

The Feilding Sewage Discharge has both positive and negative effects on the lower Oroua River, depending on the intended use. In terms of instream value maintenance, the effect is negative (discussed above). However, in terms of irrigation use, the effect is positive i.e., the irrigation water supply downstream was increased by the sewage discharge. While the diluted downstream water did not satisfy the water quality standard for environmental purposes, it could be used for irrigation purposes. This is supported by studies which have been conducted on wastewater quality and its suitability for different purposes (Middlebrooks Humenick, 1982; Pettygrove and Asano, 1985; Metcalf and Eddy, 1991; Chin and Ong, 1991; Rowe and Abdel-Magid, 1995). These include studies demonstrating that the fertilising units brought by effluents had a favourable effect on the growth of certain crops (Asano et al., 1985; Bahri, 1998). The reclaimed wastewater can be used either directly or indirectly. An example of the indirect reuse of wastewater occurs when the treated effluent is discharged and diluted in a river, then later withdrawn downstream for some beneficial use (Rowe and Abdel-Magid, 1995). Compared to other non-potable and potable uses, there is a less stringent water quality requirement for irrigation. Thus, the blending of poorer with better quality supply, thereby increasing the total quantity of usable water available, is being practised in irrigation (Ayers and Westcot, 1985). With the additional irrigation water supply from the sewage discharge, it could be concluded that there is sufficient streamflow for irrigation abstraction at the lower part of the catchment (below the sewage discharge).

The situation with regard to the Oroua River exemplified that water quantity and quality changes are related to time and location as the water flows through the basin towards its ultimate sink. While there was enough water for abstraction below the confluence of the two streams, there exists a water shortage farther downstream due to the presence of the Feilding sewage discharge. Hence, to examine a water use problem in a basin, the situation requires knowledge of both the spatial and the temporal distribution of withdrawals in the hydrographic unit under study, as well as knowledge of the natural flows at every section under examination (Manciola and Casadei, 1995). These natural flows, combined with the withdrawal values, allow the available discharges in the channels to be estimated so that they may be compared with the minimum life discharge threshold and the downstream allocation constraints.

### 6.3.2 Potential for Water Savings

In water basins, drainage water flows back into streams or to other surface and subsurface areas where it can be captured and reused as an additional source of supply. In areas where there is potential for the reuse of seepage water or runoff losses elsewhere in the basin, especially when return flows are used repeatedly downstream, solutions and investments in the upstream areas to improve localised water efficiency, thereby making more water available to upstream users, has to be traded off against lower water supplies to downstream users (Xie et al, 1993). Such investments should be evaluated from the viewpoint of water conservation in the whole basin. Improving low efficiency upstream to release more fresh water to downstream areas has a favourable environmental impact on water quality.

In the Oroua River, there are several irrigation users downstream of the Feilding discharge. This makes the return flow from the Feilding discharge an additional source of irrigation supply for the lower part of the catchment. However, the streams are being maintained not only for irrigation supply but also for contact recreation and environmental maintenance (MWRC, 1995). While the water downstream of the discharge is still usable for irrigation purposes, it has breached the prescribed standards for environmental maintenance because the Rule limits under the Manawatu Catchment Water Quality Plan for environmental protection are much higher. Consequently, the return flow was considered not as additional supply, but as additional non-process depletion.

According to Seckler (1996), the opportunities for creating real water savings lie in four principal directions:

- Increasing output per unit of evaporated water
- Reducing the pollution of water
- Reducing water losses to sinks
- Reallocating water from lower–valued to higher–valued uses

In the area under study, the first and second direction i.e., increasing output per unit of evaporated water and reducing the pollution of water, seem to be the viable options for water savings. Since the results of the analyses showed that pollution is the biggest water user in the Oroua River, the opportunity for water saving lies in reducing pollution in the streams. An alternative disposal of the Feilding sewage discharge during low flow would lessen the non-process fraction, which could mean a greater portion of the non-process depletion could be saved and tapped for other downstream uses. This may not represent new water, but would result in environmental benefits. Removal of the sewage discharge would lessen the supply for irrigation abstraction downstream, but otherwise remove the burden of water required for dilution. In the month of January, for example, while the maximum $DF_{available}$ was 1.8 indicating severe deficit, the $PF_{available}$ for the same day was only 0.31. This gap (minus the fraction depleted through open-water evaporation) represents the magnitude which could be saved with the absence of pollution from the Feilding sewage discharge

Another opportunity for water saving could be in the use of irrigation water. Irrigation abstractions, which constituted a small portion of the total depletion as compared to quality degradation (refer tables 5.4 and 5.5), may also offer an opportunity for water saving by increasing output per unit of evaporated water.

### 6.3.3 Suitability of the Water Accounting Methodology

The approach of using the measured streamflow as the inflow component for the water accounting study was able to assess the water availability in the

Oroua River. Although the streamflow was very variable, the analyses gave a clear picture of the existing state of the Oroua River during low flows. However, one drawback of the approach is that it failed to account for the other return flows. Aside from the Feilding sewage discharge, there could be other return flows from the M&I abstractions which could have seeped back into the river system.

The Water Accounting Methodology (Molden, 1997) did not include pollution in the analyses. While the methodology took into account the return flows for reuse by downstream users, the reduction of the water's productivity due to changes in water quality was not taken into account. However, in his report, he emphasised the importance of water quality in water depletion and water productivity, and the requirements for a means of accounting for depletion due to pollution. Accounting for pollution is very important because, while it is non-consumptive in the physical sense, it does alter the resource–and may render it unsuitable for subsequent consumptive uses. This is true especially in water basins being maintained for their instream values, where a stringent water quality standard is observed.

Hence, in addition to the original report of Molden (1997), depletion due to pollution should be included in the analysis. To account for depletion due to pollution, the method described by Keller and Keller (1995) could be used. In this method, the physical amount of water lost to pollution from the discharge of effluents is measured by the amount of upstream water which would be required to dilute it back down to the maximum allowed concentration of pollutants (see methodology section). This would not work in the case of heavy metals or other toxic elements–which must simply be prohibited from entering the water stream. However, it provides a reasonable, if rough, measure of the damage to water by ordinary forms of pollution (Seckler, 1996) This method of estimating the amount of water lost to pollution is analogous to the dilution factor suggested by Hickey et al. (1989a, 1989b). Hickey and co-authors pioneered the calculation of dilution factors required in receiving streams as a means of assessing the pollution potential of organic wastewater. Dilution factors are calculated by dividing the characteristic concentrations of various pollutants by established guidelines for maintaining suitability of streams for various water uses. The difference of the dilution factors calculated by Hickey et al. is that they assumed no background water contamination resulting in lower values.

## 6.4 Conclusions

Based on the results of the analyses, the following conclusions were derived:

- The approach of using the measured streamflow as inflow components for the water accounting study could be used to assess the water availability in the lower portion of the Oroua River. The indicators gave a clear picture of the existing state of the river during the summer months. However, one limitation of the approach is that it did not account for the other return flows. Aside from the Feilding sewage discharge, there could be other return flows from the irrigation and M&I diversions.

- Water depletions from instream uses which include waste assimilation, environmental maintenance, and free-water evaporation, comprised the largest part of the total streamflow depletions in the study area. In some instances, combined depletion from waste assimilation and free-water evaporation was more than 3 times the available water. Depletions from offstream uses, including municipal, industrial, and irrigation abstractions, comprised only a small portion of the total streamflow depletion.

- The analysis proved, further, that there was water scarcity in the Oroua River during the summer months. While the assessment showed sufficient streamflow for the different M&I use downstream of the Kiwitea Stream confluence, the flow was not enough to assimilate the sewage discharge from the Feilding Sewage Treatment Plant. Water quality in the lower catchment does not meet the requirements set for the maintenance of contact recreation due to insufficient streamflow for waste assimilation during low flows.

# CHAPTER VII

# ANALYSIS WITHOUT THE FEILDING SEWAGE DISCHARGE

## 7.1 Introduction

The previous analyses showed that water pollution from the Feilding sewage discharge is the biggest single streamflow consumer in the Oroua River (refer to figures 6.4 to 6.6). While the sewage discharge added to the streamflow, it brought the stream into unacceptable quality for instream values. This chapter presents the water accounting analysis without the Feilding sewage discharge during low flows i.e., the Feilding sewage flow is applied to land and the whole flow is transpired by plants.

## 7.2 Results

The results of the analysis without the Feilding sewage discharge are shown in figures 7.1 to 7.3. Presented are the results from January to March, the months most affected by pollution due to the very low flow prevailing during these periods. The figures show that withdrawal of the Feilding sewage discharge resulted in 'additional' water. Contrary to the situation when the pollution effect was present (which showed water deficit), the whole period showed a surplus of available water with a maximum $DF_{available}$ of only 0.43, 0.75, and 0.77 for January, February and March respectively. This increase of available water arises from the removal of water needed for dilution, which was estimated at 86,429 $m^3$/day (refer section 5.2.1.4). The low values of $DF_{available}$ show that, while further abstraction upstream of the Kiwitea confluence is a remote possibility due to the limited streamflow and over-concentration of abstractions in that portion of the river (refer section 6.2.2), further downstream abstraction could be allowed without adverse environmental effects. This means that without the Feilding sewage discharge, the streamflow (which is insufficient to assimilate the discharges) could easily satisfy the minimum streamflow of 897 l/s set for environmental maintenance and, at the same time, be able to supply the different abstractions. This effective minimum flow was set in the Oroua Catchment Water Allocation and River Flows Regional Plan, which specified that when the suspension of some abstractions takes effect, flows downstream of the abstractions will fall to 897 litres per second.

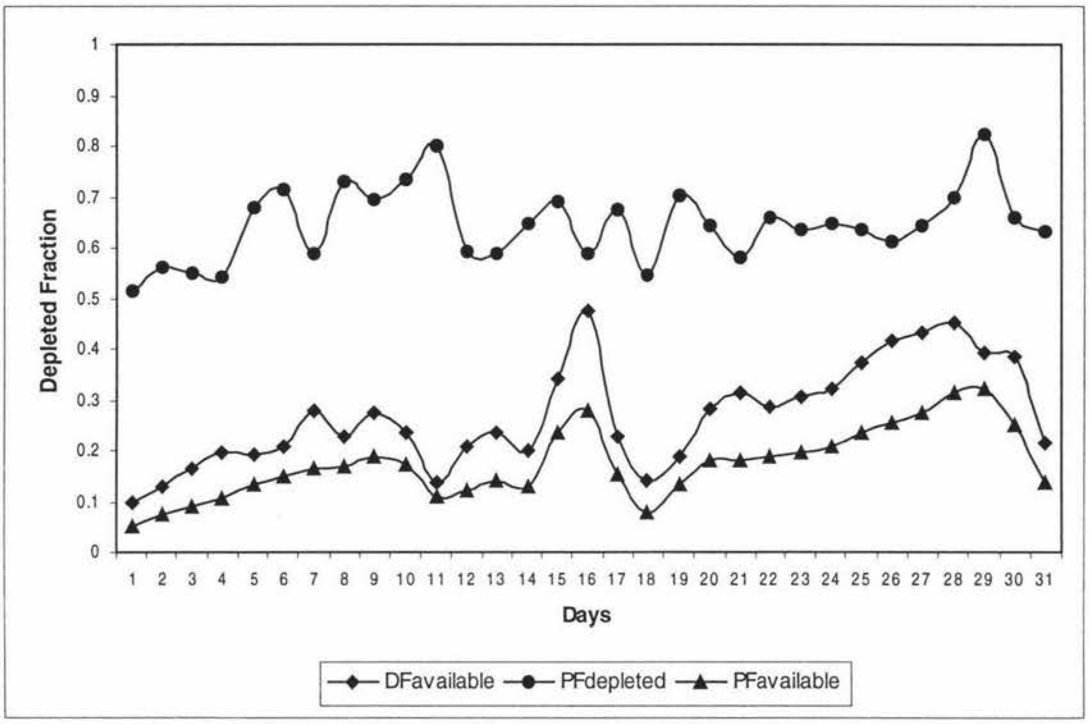



**Figure 7.1: Streamflow Depletion for the Month of January without the Feilding Sewage Discharge**

The results showed an increase in the process fraction. It should be noted that although the $DF_{available}$ decreased, the $PF_{depleted}$ increased considerably (figures 7.1 to 7.3). The higher values of $PF_{depleted}$ were observed in days with lower recorded evaporation. This is true–since without the Feilding sewage discharge, the only non-process depletion of the streamflow came from open-water evaporation. Thus, lower evaporation means higher process fraction ($PF_{depleted}$). The $PF_{depleted}$ increased with some days showing as high as 0.9 (figure 7.2) an indication that a large part of the streamflow was beneficially used.

On the other hand, some days showed $PF_{depleted}$ values below 0.6. These low values correspond to days with higher recorded evaporation–indicating that, on dry-sunny days, free-water evaporation consumes a substantial amount of streamflow, which, in some instances, consisted of almost 50% of the total depletion. This seems to indicate water saving opportunities of about 50% of the total depleted water. However, since non-process depletion is comprised of free-water evaporation only, conservation measures to reduce non-beneficial evaporation would probably be a very expensive undertaking, since it would require a conservation programme for the entire river. It should also be emphasised that the $PF_{depleted}$ values could be even higher, since the evaporation might have been overestimated (as the area was based on an average stream width of 25 metres).

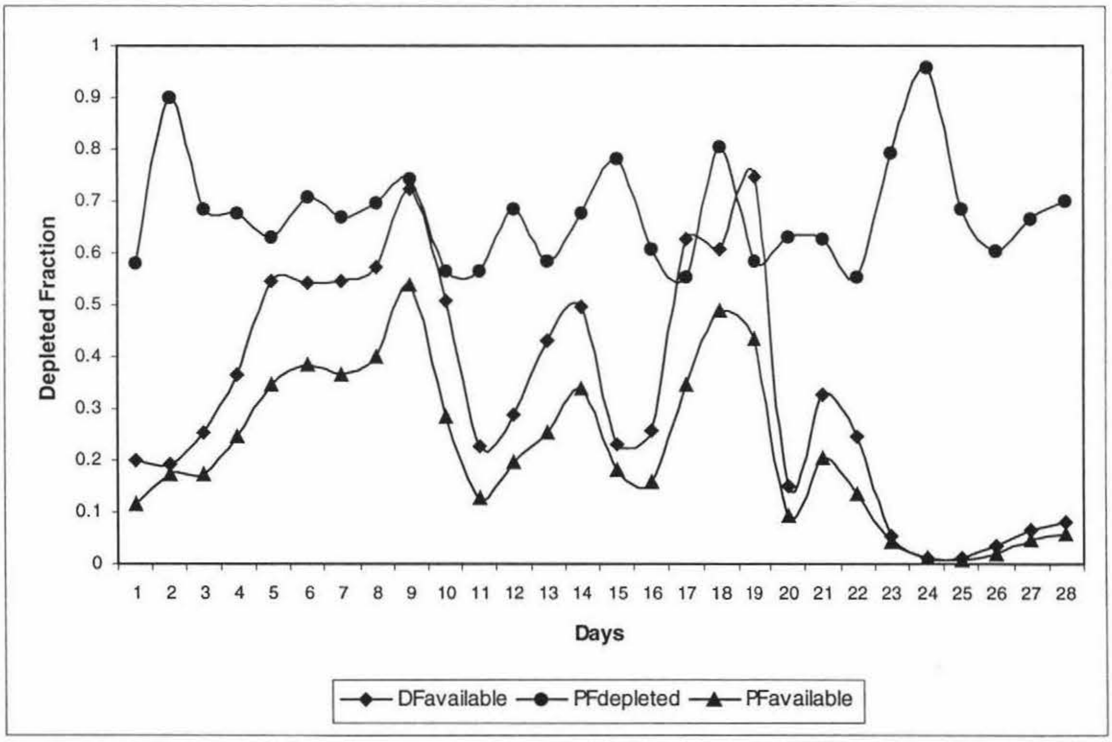



**Figure 7.2: Streamflow Depletions for the Month of February without the Feilding Sewage Discharge**

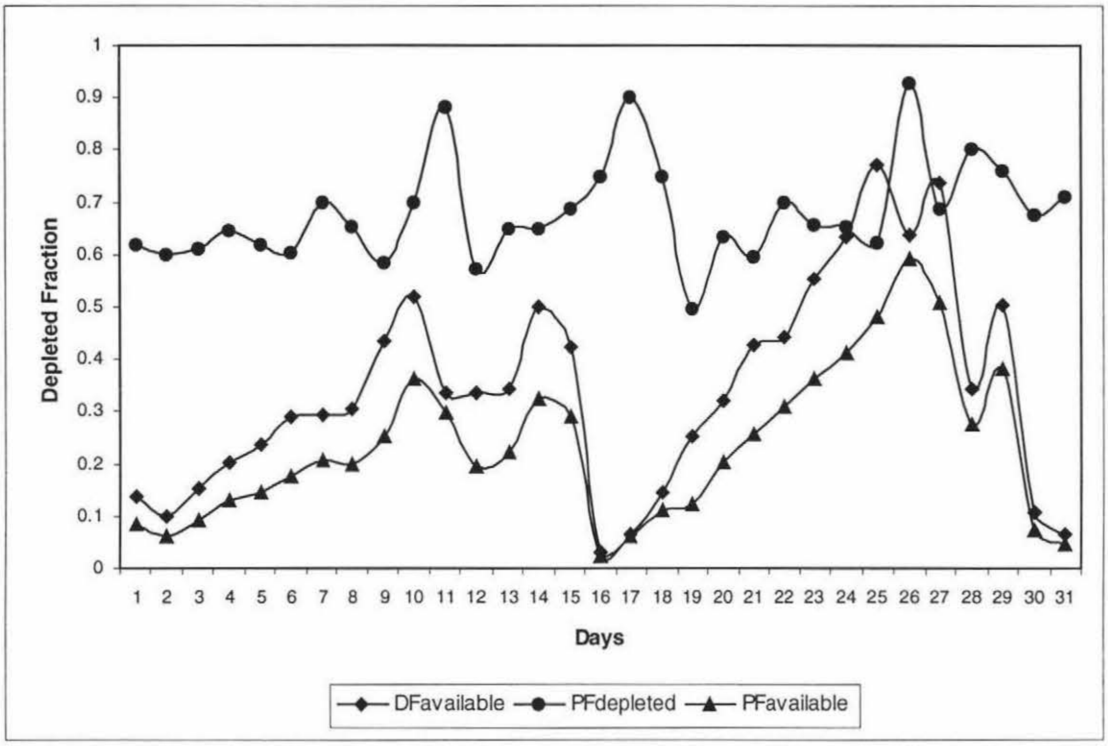



**Figure 7.3: Streamflow Depletions for the Month of March without the Feilding Sewage Discharge**

## 7.3 Discussion

The analysis showed that the absence of the Feilding sewage discharge greatly 'increased' the available streamflow in the lower part of the Oroua River. Withdrawal from discharging sewage into the river resulted in additional water for further abstractions. This is true because, while the pollution does not physically deplete water, it degrades it to a quality unsuitable for certain uses. Hence, as pointed out earlier, while withdrawal of the sewage discharge from the river did not present new water, it eliminated the burden of water required for dilution (refer section 5.2.4). In addition, withdrawal of the Feilding sewage discharge would result in a higher downstream water quality–such as would be able to assimilate agricultural seepage and other minor discharges at the lower part of the catchment without adverse effects upon the stream's instream values.

Dilution was necessitated by the low level of treatment achieved by treatment plants, which proved to be inadequate to safeguard the quality of streams and rivers, with high dilution being required to assimilate the discharges safely. The treated effluents may still retain large concentrations of organic matter, nutrients such as nitrogen (N) and phosphorus (P), and other contaminants (Hauber, 1995). Discharging wastes to waterways can result in water quality degradation such as eutrophication, depletion of dissolved oxygen, chemical toxicity, and salinity. Hickey et al. (1989) on potential impacts of domestic sewage on rivers reported that dilution based on the 95 percentile ranged from 11-fold to >1100-fold, with the highest value being associated with the restriction of algal proliferation immediately below discharges, and with bacterial quality with respect to recreational bathing. Maintenance of receiving water concentrations below existing criteria for 95% of the time would require >1100-fold dilution for coliforms (bathing criterion), >115-fold for coliforms (post-treatment drinking criterion), and >950-fold dilution to prevent clarity impacts on clear water.

In the Oroua River, MWRC (1995) reported that, while BOD and Ammonia levels downstream of the Feilding sewage discharge are within the Rule limits for water clarity, Suspended Solids and Dissolved Reactive Phosphorus have been exceeded. Dissolved Reactive Phosphorus registered the highest impact, exceeding the Rule limit by up to 40-fold. These show that, while the performance of the Feilding Treatment Plant improved after its upgrading (MWRC, 1995), the low river flow proved to be inadequate to assimilate the sewage discharge safely. This is true since reduction in volume in a river reduces its capacity to dilute and break down inputs of nutrients, toxic substances and organic material. Therefore, reductions in flow upstream of these substances leads to their increased concentration (MfE, 1997). Further, while the Feilding effluent is better now than it was a few years ago, "the environmental standards are going up and up all the time" (Jackson, 1998).

On the other hand, the withdrawal of the Feilding sewage discharge would result in a lesser irrigation water supply for downstream users. This is true because, while the diluted sewage water did not meet the environmental water quality standard, it could be used for irrigation due to the less stringent water quality standard observed for irrigation (refer section 6.3.1). However, most of the irrigation abstractions are located upstream of the sewage discharge. From the 16 irrigation abstractions with resource consents, only one is located below the sewage discharge. Hence, the reduction of the streamflow has minimal effect upon the downstream irrigation water supply.

### 7.4 Conclusion

From the analysis, withdrawal of the Feilding sewage discharge would result in increased available water for the lower part of the Oroua River due to the elimination of the water needed for waste assimilation. This would result to a surplus of available water during the critical months, with maxima $DF_{available}$ of only 0.43, 0.75 and 0.77 for January, February and March respectively. The effective minimum flow set for instream values of 897l/s could be satisfied. In addition, withdrawing the Feilding sewage discharge could mean higher downstream water quality, which could then easily assimilate other non-point source discharges such as seepage from agricultural lands and other minor point discharges.

# CHAPTER VIII

# CONCLUSIONS AND RECOMMENDATIONS

## 8.1 Conclusions

The main point of the water accounting methodology is that it does not simply consider the diverted water but also the actual use of these diversions. By considering the actual depletions, instead of the traditional approach of using the amount diverted, the return flow i.e. that part of the diversions which was not depleted would be accounted for in the resulting outflow. However, this was not reflected in the study due to the fact that limited data only were available. Had the first analysis (the basin-wide water accounting) been successful, the amount of return flow from the different abstractions would have been accounted for. Despite the limitations of the study, the use of the indicators helped in understanding the situation by the following:

**First, the Depleted Fraction ($DF_{available}$) indicator showed clearly how much further abstraction is allowed.**

- It maybe obvious that removing a certain depletion would result in an increase in uncommitted outflow. This is very evident when the water was physically depleted, since the maximum depletion would be 100 percent. In this case, the amount of depletion saved would mean additional uncommitted outflow equal to that amount. However, when pollution is included–especially when the total depletion exceeded the available water as in the case of the Oroua River–removing the Feilding sewage discharge does not mean that there would be additional water equal to the amount depleted by it. Hence, there is a difficulty in determining the resultant uncommitted outflow. This difficulty of determining the added outflow was simplified by the Depleted Fraction ($DF_{available}$) indicator. The indicator showed clearly how much of the available flow could be further abstracted after the sewage discharge had been withdrawn.

**Second, the Process Fraction indicator ($PF_{depleted}$) showed the efficiency of the system.**

- The use of the $PF_{depleted}$ readily shows an opportunity for better use of water.

The following conclusions were derived from the study:

- The use of the water accounting methodology in assessing water availability for the whole basin requires more rainfall recording stations–especially at the State Forest Park, where most of the streamflow (approximately 80%) comes from during low flows (MWRC, 1997). A more accurate catchment model is needed in order to have a reliable streamflow estimate. Further, streamflow measurement at the mouth of the river is recommended both to account for the return flows from upstream uses, and for use in further validation of the estimated streamflow.

- By using the approach of the measured streamflow as the inflow component for the water accounting study, it was possible to assess the water availability in the lower portion of the Oroua River; for the indicators gave a clear picture of the existing state of the river during the summer months. However, one limitation of the approach was that it did not account for the other return flows. Aside from the Feilding sewage discharge, there are other unaccounted return flows from irrigation and M&I diversions.

- Water depletions from instream uses which include waste assimilation, environmental maintenance, and free-water evaporation, comprised the largest part of the total streamflow depletions in the lower Oroua River. In some instances, combined depletion from waste assimilation and free-water evaporation was more than 3 times the available water. Depletions from offstream uses, including municipal, industrial, and irrigation abstractions comprised only a small portion of the total streamflow depletion.

- The study proved, further, that there was water scarcity in the Oroua River during the summer months. While the assessment showed sufficient streamflow for the different M&I use downstream of the Kiwitea Stream confluence, the flow was not sufficient to assimilate the sewage discharge from the Feilding Sewage Treatment Plant. Water quality in the lower catchment did not meet the requirements set for the maintenance of contact recreation due to the fact that insufficient streamflow was available for waste assimilation during low flows.

- Withdrawal of the Feilding sewage discharge would result in an increase of uncommitted outflow for the lower part of the Oroua River due to the elimination of water needed for waste assimilation. Withdrawing the Feilding sewage discharge would mean higher downstream water quality, so that other non–point source discharges such as seepage from agricultural lands and other minor point discharges could be easily assimilated. On the other hand, this withdrawal would mean a lesser irrigation water supply for downstream users.

- The study showed that accounting for the pollution effect could be included in the original water accounting methodology of Molden (1997). The pollution effect of different contaminants could be quantified by its dilution factor i.e., the physical amount of water lost to pollution from the discharge of effluents is measured by the amount of upstream water which would be required to dilute it back down to the maximum allowed concentration of pollutants.

## 8.2 Recommendations

### 8.2.1 For the Future use of the Water Accounting Methodology

- Accounting for the pollution effect should be included also in the original water accounting analyses of Molden (1997). The pollution effect of different contaminants could be quantified by its dilution factor i.e., the physical amount of water lost to pollution from the discharge of effluents could be measured by the amount of upstream water which would be required to dilute it back down to the maximum allowed concentration of pollutants.

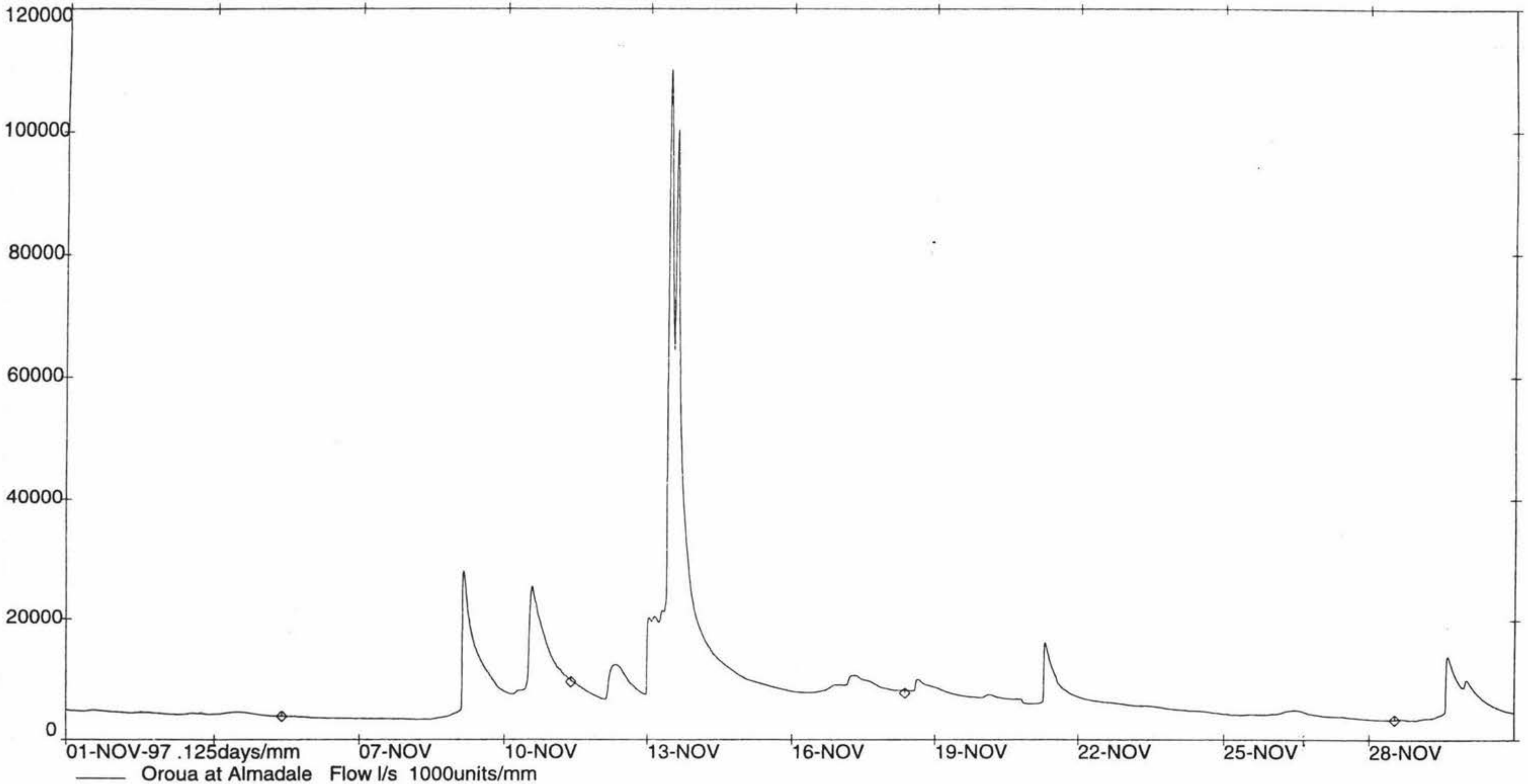
- There is a need for further documentation on the depletion of water from M&I abstractions, and the returns from this use.

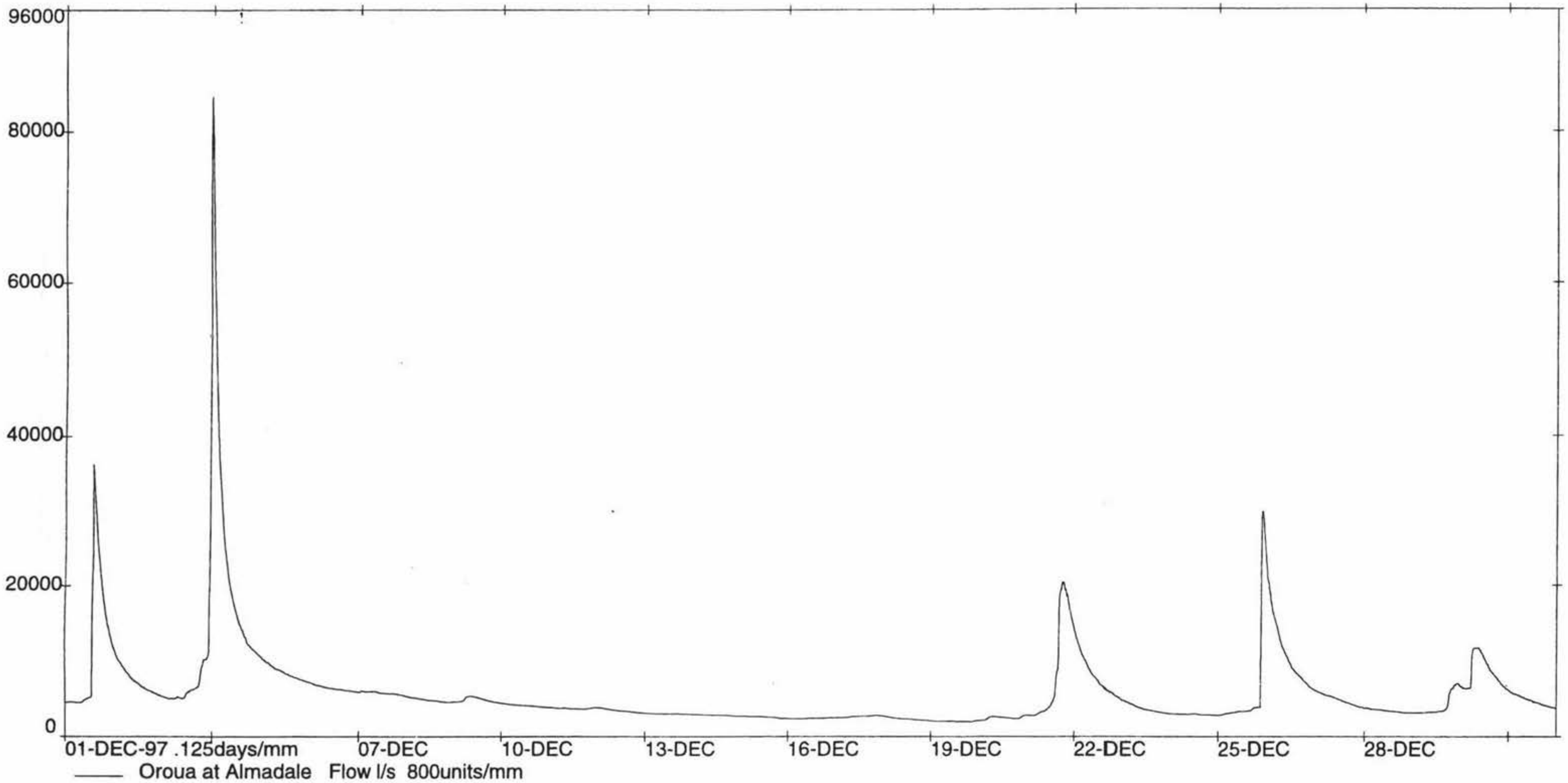
### 8.2.2 For the Management of the Oroua River

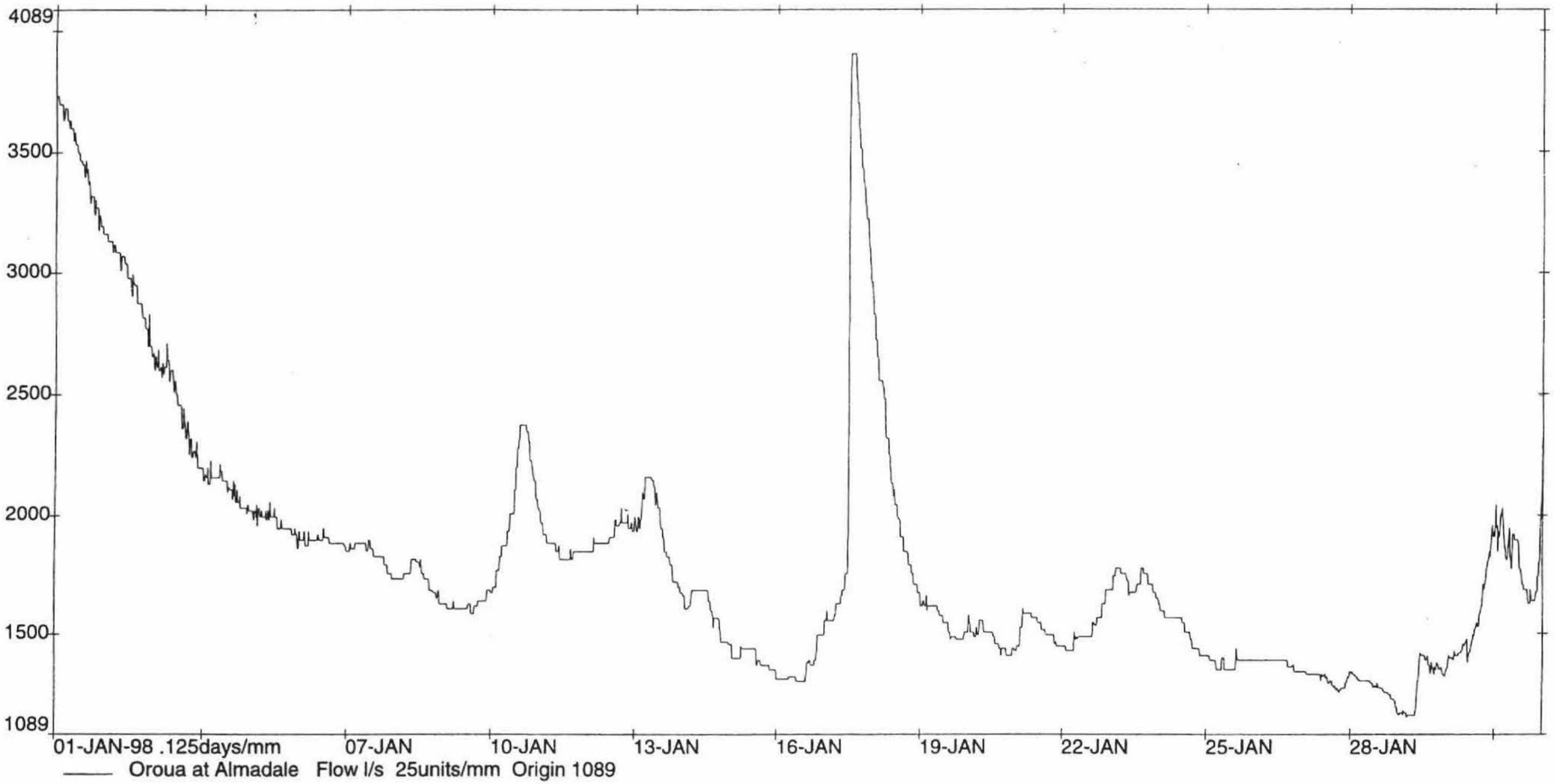
There is a need for regional councils to have actual data on abstractions e.g. Resource Consents require flow meters. Finally, in addition to the MWRC (1995), it is recommended that the Feilding sewage discharge be withdrawn for alternative disposal during times of low river flows.

# APPENDICES

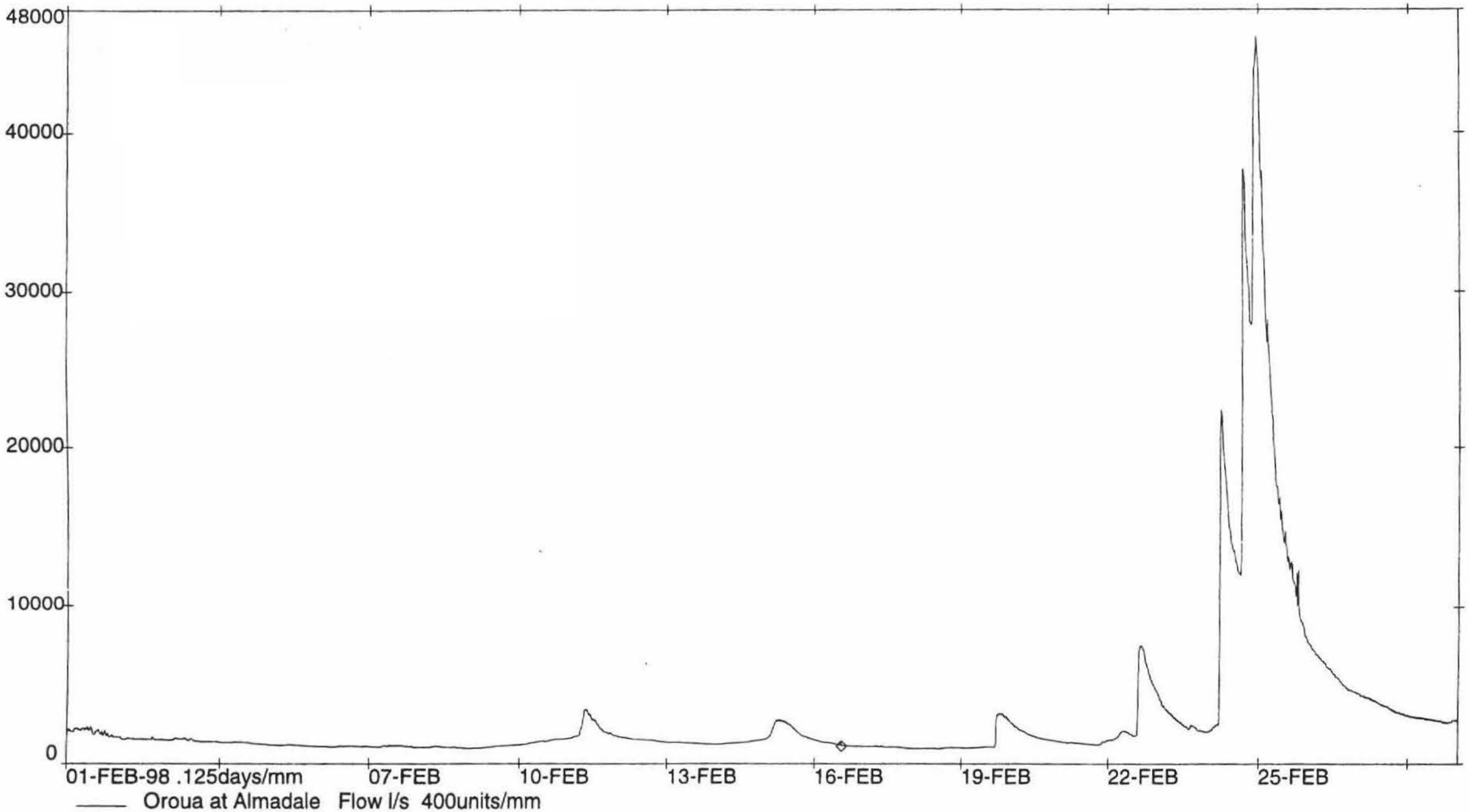
**Appendix 1: Hydrographs showing the Oroua River streamflow at Almadale from November 1997 to March 1998 (Source: MWRC).**

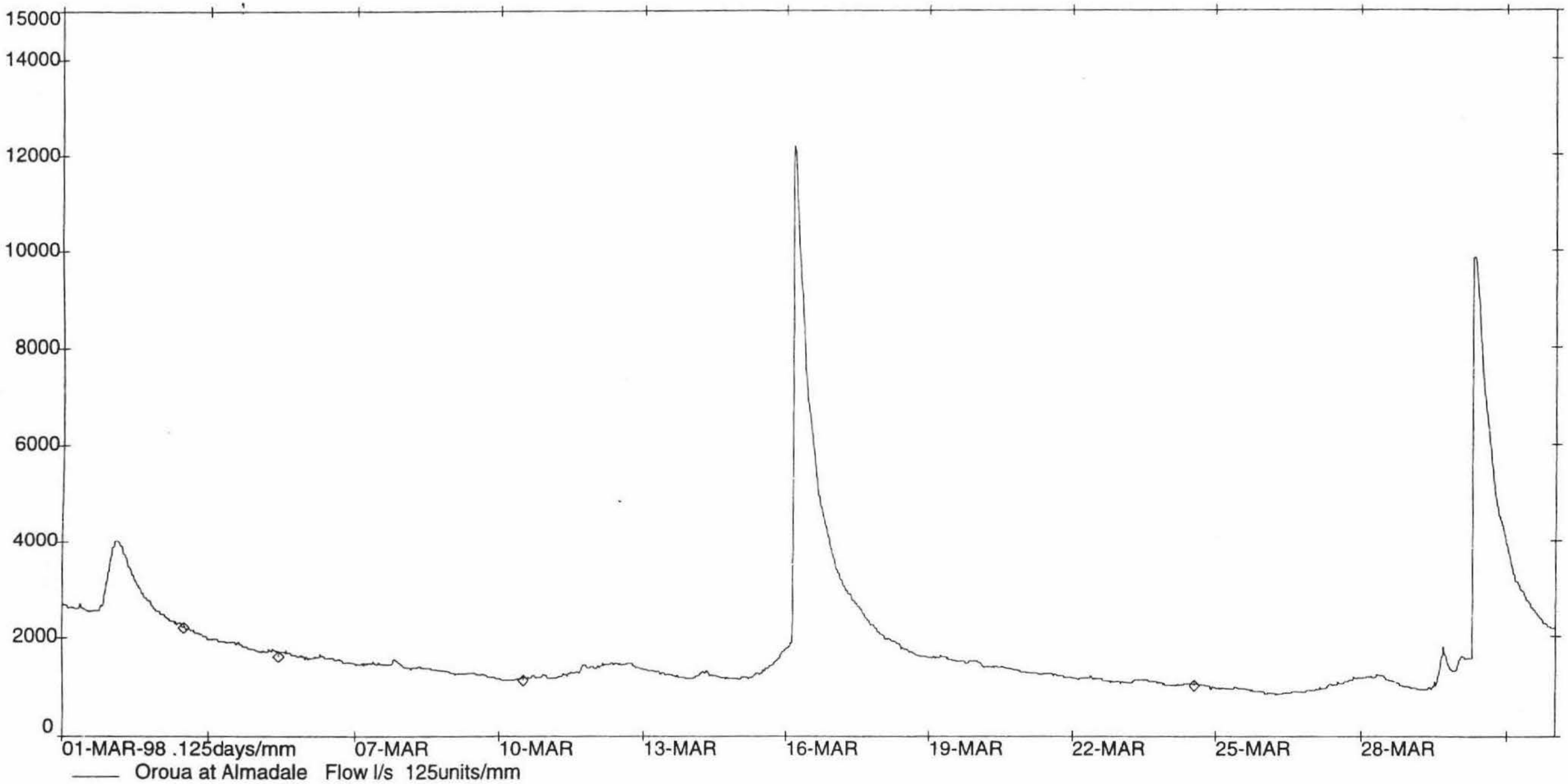

120000
100000
80000
60000
40000
20000
0
01-NOV-97 .125days/mm
07-NOV
10-NOV
13-NOV
16-NOV
19-NOV
22-NOV
25-NOV
28-NOV
Oroua at Almadale Flow l/s 1000units/mm


96000
80000
60000
40000
20000
0
01-DEC-97 .125days/mm
07-DEC
10-DEC
13-DEC
16-DEC
19-DEC
22-DEC
25-DEC
28-DEC
Oroua at Almadale Flow l/s 800units/mm



4089
3500
3000
2500
2000
1500
1089
01-JAN-98 .125days/mm
07-JAN
10-JAN
13-JAN
16-JAN
19-JAN
22-JAN
25-JAN
28-JAN
Oroua at Almadale Flow l/s 25units/mm Origin 1089


48000
40000
30000
20000
10000
0
01-FEB-98 .125days/mm
07-FEB
10-FEB
13-FEB
16-FEB
19-FEB
22-FEB
25-FEB
Oroua at Almadale Flow l/s 400units/mm


15000
14000
12000
10000
8000
6000
4000
2000
0
01-MAR-98 .125days/mm
07-MAR
10-MAR
13-MAR
16-MAR
19-MAR
22-MAR
25-MAR
28-MAR
Oroua at Almadale Flow l/s 125units/mm

## Appendix 2: Daily Kiwitea Stream Streamflow at Spur Road from April 1997 to March 1998 (Source: MWRC)

| Day | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 459 | 1667 | 1043 | 1698 | 1383 | 2118 | 8242 | 1209 | 992 | 392 | 275 | 359 |
| 2 | 415 | 1486 | 1274 | 2882 | 2345 | 1868 | 5864 | 1112 | 761 | 334 | 231 | 289 |
| 3 | 396 | 1352 | 2409 | 4706 | 1971 | 3385 | 4202 | 1046 | 2402 | 292 | 252 | 243 |
| 4 | 385 | 1241 | 1233 | 3393 | 1583 | 3482 | 3232 | 994 | 4274 | 270 | 233 | 219 |
| 5 | 393 | 1128 | 6925 | 2595 | 3893 | 2314 | 1363 | 888 | 1679 | 270 | 210 | 195 |
| 6 | 413 | 1041 | 4856 | 2170 | 3034 | 1784 | 1743 | 804 | 981 | 273 | 199 | 182 |
| 7 | 473 | 962 | 3261 | 1877 | 2190 | 1519 | 1099 | 775 | 793 | 284 | 194 | 170 |
| 8 | 420 | 918 | 2444 | 1681 | 1770 | 1389 | 6662 | 859 | 659 | 271 | 185 | 173 |
| 9 | 5394 | 874 | 2023 | 1593 | 1530 | 1275 | 4781 | 2115 | 636 | 262 | 181 | 159 |
| 10 | 5501 | 824 | 1758 | 2800 | 1377 | 1165 | 3898 | 2680 | 632 | 337 | 292 | 157 |
| 11 | 2429 | 777 | 1700 | 5482 | 1300 | 1117 | 4641 | 2304 | 597 | 336 | 306 | 192 |
| 12 | 2441 | 753 | 1563 | 3056 | 1806 | 1431 | 3415 | 1313 | 502 | 368 | 215 | 250 |
| 13 | 1576 | 789 | 1459 | 2383 | 1820 | 1668 | 2671 | 3043 | 444 | 342 | 207 | 218 |
| 14 | 4573 | 843 | 1470 | 2961 | 2816 | 1247 | 3455 | 2471 | 403 | 275 | 211 | 188 |
| 15 | 3044 | 849 | 1319 | 4119 | 3672 | 978 | 2413 | 1343 | 367 | 255 | 295 | 222 |
| 16 | 2863 | 783 | 1182 | 3079 | 2659 | 893 | 8590 | 1267 | 357 | 256 | 240 | 461 |
| 17 | 5433 | 692 | 1106 | 2508 | 2152 | 835 | 5477 | 1259 | 452 | 404 | 210 | 257 |
| 18 | 3160 | 637 | 1834 | 2480 | 1801 | 1732 | 4196 | 1511 | 373 | 329 | 184 | 227 |
| 19 | 3526 | 601 | 2393 | 2437 | 1733 | 1815 | 3558 | 1046 | 352 | 283 | 211 | 199 |
| 20 | 6448 | 576 | 1775 | 2148 | 2542 | 1156 | 4326 | 851 | 585 | 306 | 194 | 179 |
| 21 | 3943 | 562 | 1465 | 1948 | 2134 | 974 | 5678 | 958 | 1227 | 293 | 180 | 163 |
| 22 | 2726 | 549 | 1338 | 1716 | 1805 | 959 | 8250 | 841 | 1242 | 302 | 697 | 155 |
| 23 | 8538 | 547 | 1242 | 1662 | 1411 | 4942 | 4281 | 695 | 671 | 329 | 334 | 152 |
| 24 | 1146 | 900 | 1357 | 1603 | 2030 | 1171 | 3310 | 598 | 508 | 272 | 1902 | 154 |
| 25 | 5346 | 1460 | 2902 | 1453 | 7622 | 4087 | 2520 | 548 | 801 | 263 | 2412 | 156 |
| 26 | 4680 | 1019 | 2002 | 1283 | 5058 | 2565 | 2741 | 675 | 1055 | 257 | 878 | 161 |
| 27 | 3631 | 1208 | 4035 | 1171 | 4053 | 1985 | 2643 | 568 | 747 | 237 | 438 | 195 |
| 28 | 2860 | 965 | 2924 | 1179 | 3949 | 1870 | 2080 | 496 | 461 | 223 | 319 | 199 |
| 29 | 2303 | 777 | 2194 | 1132 | 3773 | 2205 | 1778 | 928 | 497 | 255 | | 225 |
| 30 | 1904 | 697 | 1854 | 1072 | 2871 | 1351 | 1533 | 812 | 829 | 294 | | 481 |
| 31 | | 776 | | 1205 | 2408 | | 1344 | | 491 | 375 | | 351 |
| Min | 385 | 547 | 1043 | 1072 | 1300 | 835 | 1344 | 496 | 352 | 223 | 180 | 152 |
| Mea | 3238 | 911 | 3237 | 2306 | 3596 | 2599 | 5793 | 1200 | 863 | 298 | 417 | 224 |
| Max | 1146 | 1667 | 2409 | 5482 | 2030 | 1351 | 2413 | 3043 | 4274 | 404 | 2412 | 481 |

The above figures are in litres per second

## Appendix 3: Available Soil Water Capacity

Manawatu soils are generally classified as dense grey soils and are texturally classified as silt loam (Molloy, 1993). The estimated rooting depth for pasture was 0.4 metre (McFetridge, 1997) while the rooting depth for the forested area was estimated to be 1 metre (Gasson and Cutler, 1990). Using both the information in the table below and the estimated rooting depths, Available Water Capacity (AWC) was calculated for both areas.

**Pasture:** 0.3 m x 220 mm/m = 66 mm

0.1 m x 150 mm/m = 15 mm

**Total AWC = 81 mm**

**Forested Area:** 0.3 m x 220 m/mm = 66 mm

0.7 m 150 mm/m = 105 mm

**Total AWC = 171 mm**

**Mean available water-holding Capacities of soils of various textural classes (NZS 5103, 1973)**

| Textural Class | Water Available mm/m depth soil | |
|---|---|---|
| | Up to 0.3 m | Below 0.3 m |
| Sand | 150 | 50 |
| Loamy Sand | 180 | 110 |
| Sandy loam | 230 | 150 |
| Fine Sandy Loam | 220 | 150 |
| Silt Loam | 220 | 150 |
| Clay Loam | 180 | 110 |
| Clay | 175 | 110 |
| Peat | 200 to 250 | at least 200 to 250 |

## Appendix 4: Monthly Climatic Water Balance

The table below illustrates the monthly climatic water balance which was used to calculate the actual evapotranspiration, change in soil moisture storage, and runoff in the basin-wide analysis (chapter V).

**Monthly Climatic Water Balance for a Catchment near Palmerston North. (Source: Wall, 1998)**

Location: PN  $SMS_c$: 150mm  RO: 0.5  Catchment Area: 200ha

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P | 79 | 67 | 69 | 81 | 89 | 97 | 89 | 89 | 75 | 88 | 78 | 94 | 995 |
| PET | 118 | 100 | 81 | 46 | 28 | 17 | 18 | 29 | 46 | 69 | 90 | 139 | 781 |
| P-PET | -39 | -33 | -12 | 35 | 61 | 80 | 71 | 60 | 29 | 19 | -12 | -45 | 214 |
| SMS | 79 | 63 | 58 | 93 | 150 | 150 | 150 | 150 | 150 | 150 | 138 | 102 | - |
| ΔSMS | -23 | -16 | -5 | 35 | 57 | 0 | 0 | 0 | 0 | 0 | -12 | -36 | - |
| AET | 102 | 83 | 74 | 46 | 28 | 17 | 18 | 29 | 46 | 69 | 90 | 130 | 732 |
| Deficit | 16 | 17 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 49 |
| Surplus | 0 | 0 | 0 | 0 | 4 | 80 | 71 | 60 | 29 | 19 | 0 | 0 | 263 |
| TARO | 7 | 3 | 1 | 0 | 4 | 82 | 112 | 116 | 87 | 62 | 31 | 15 | - |
| Run Off | 4 | 2 | 1 | 0 | 2 | 41 | 56 | 58 | 44 | 31 | 16 | 8 | 263 |
| Detention | 3 | 1 | 0 | 0 | 2 | 41 | 56 | 58 | 43 | 31 | 15 | 7 | - |

Where:

P = Precipitation

PET = Potential Evapotranspiration

SMS = Soil Moisture Storage

AWC = Available Water Capacity

AET = Actual Evapotranspiration

ΔSMS = Change in Soil Moisture Storage

$SMS_C$ = Soil Moisture Storage Capacity of the Soil

When $P - PET < 0$, $$\Delta SMS = SMS\left[e^{\left(\frac{P-PET}{SMS_C}\right)} - 1\right]$$

and $AET = P - \Delta SMS$

When $P - PET \geq 0$, $\Delta SMS = P - PET$

and $AET = PET$

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