The Impact of Bushfires on Water Quality

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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DECLARATION

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.
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SUMMARY OF THE RESEARCH

Population growth in urban areas leads to a higher demand in water use. Quality of water is an important factor not only from an aesthetic view, but also for ecological health purposes.

This thesis presented research that is designed to develop a spatial approach to support the planning of the water quality in the areas subjected to bushfires, using a case study from state of Victoria. In particular, this research involved the implementation of a hydrological model in order to predict the river water quality, to assist in the decision-making process.

The impact of bushfires on water quality can be highly variable most of the individual water quality parameters. This variability is caused by a number of landscape influences and climatic factors, most notably rainfall. High magnitude and intense rainfall events soon after fire generate the largest impacts on water quality and sometimes trigger extreme erosion events.

There are many important water quality parameters that must be taken into account when the water is delivered to the population. For some of the water quality parameters there is very little information available, which makes it difficult to draw conclusions about bushfire impacts.

The monitoring campaigns are very expensive, and better options are the modeling tools.

The model used in this research is eWater, a conceptual, semi-distributed model, which applies the flow accumulation principles. eWater Source - Australia's National Hydrological Modeling Platform (NHMP) – is developed by eWater CRC, Australia. It is designed to simulate all aspects of water resource systems to support integrated planning, operations and governance from urban, catchment to river basin scales including human and ecological influences.

The catchment analyzed can be divided into sub-catchments and functional units. The model integrates rainfall runoff, constituent generation and filter models, which are parameterized. The user must find the best set of parameters that is suitable for that catchment. After calibration and validation, the model can be used in the same catchment for any period of time, and it will be able to predict the pollution levels in the catchment, with a good accuracy. Also, a user can follow the same steps, to calibrate

the model for any other catchment. This method is time consuming, but it does not require many input data.

The fires and the rain are classified in 3 classes each. Then, the landuse, the burnt areas and the areas with rain are combined and parameterized separately.

The outputs from the developed model are good correlated with the measured data, and show higher concentrations of suspended sediment and nutrients after bushfire followed by rain. To improve the model performance, the measured water quality data must be daily data with a better accuracy.

1. INTRODUCTION

1.1. Introduction

This thesis is an assessment of the influence of bushfires on chemical river water parameters, in the State of Victoria, Australia.

Wetlands including rivers have unique structural and physical-chemical processes that distinguish them from other ecosystems (Kingsford, 2009). Each wetland is unique and its processes are dependent on its hydrology. This is the most important factor which determines water's structural composition, physical and chemical processes (Banks and Docker, 2014). Wetlands with their hydro-geographic and ecological characteristics have a vital role with various functions in the environment (Leibowitz, 2003). They can be considered as a resource by themselves but within them there are many other resources that are very valuable to the humanity (Department of Environment and Primary Industries, 2013). Their ability to provide sustainable resources to support other ecosystems, to provide food and to sustain their fundamental ecological functions is closely linked to their biological, physical and chemical characteristics plus the processes arising from the interactions of these characteristics (Shenton, 2012). Negative impacts on the wetlands can have dramatic effects, often altering irreversibly the structural factors and features of the wetland ecosystem (Ni and Qin, 2001).

In arid areas, wetlands have diverse and pivotal functions, being used as habitat for wild animals, food support and balance (Bunn and Arthington, 2002). Also, the wetlands have the capacity to make the ground water recharge and discharge, nutrient exchange with other ecosystems (Bullock and Acreman, 2003). In these areas, wetlands are multi-product producing systems, providing a number of benefits to people and ecosystems (Millennium Ecosystem Assessment Panel, 2005). They have high biological diversity contents and have a great importance in supporting the arid environments situated close by them (Kingsford and Thomas 2004, Wen et al., 2009). They are centres of biodiversity containing rare species and, in some cases endemic species (Department of Environment and Energy, 2013).

Water availability, fertile lands and their assets have attracted human settlement and exploitation of wetlands, throughout history (Food and Agriculture Organization of the United Nations and Earthscan, 2011).

Numerous land and water use activities could have an impact on a variety of goods and services that may be derived from the aquatic ecosystems in an area (UNEP, 2010). These stressors include intensive coal mining activities, coal-fired power generation, industrial activities and agriculture, combined with a general decline in the operation and management of wastewater treatment infrastructure (sewage treatment) (Hana at al., 2014, Hobbs et al., 2008; Wang, 2001, Worrall and Burt, 1999). The water pollutants generated by these activities include general acidification of the system, the increase of heavy metal ions plus sulphates and other contaminants via acid mine drainage; potential acid rain which is a result of polluted air; industrial emissions containing a variety of potential pollutants; big quantities of nutrients (phosphorus and nitrogen) and microbiological pollution from agriculture and sewage effluent (Haygarth et al., 2012; Cournane et al., 2011; Kleinman et al., 2011; Kato et al., 2009; Csatho´ and Sisa´k, 2007; Li and Zhang, 2010). Associated with these, the concentrations of the water quality parameters if regularly exceeded can result in harmful impacts on aquatic ecosystems and human health (Paredes-Arquiolaa et al., 2014; Rashid and Romshoo, 2013).

Increasing population in urban areas leads to a higher demand in water supply (Chen et al., 2014). The quality of water is a very important factor not only from the aesthetic point of view, but also for health purposes (Wood et al., 2015). There are many significant water quality parameters that must be taken into account when the water is delivered to a population (World Health Organization, 1997). Land use influences many water chemical parameters especially in the areas subjected to bushfires (Smith et al., 2011a). The fires burn away the vegetation from the catchment and alter the soil properties (Zavala et al., 2014). Then, if it rains, it leads to erosion and the debris is transported into rivers and leads to poor water quality (Moody and Martin, 2001, 2009; Reneau et al., 2007; Sheridan et al., 2008; Lane et al., 2008; Wilkinson et al., 2009, White et al., 2006).

The most efficient way of conserving water sources is to apply appropriate management to decrease the erosion and to find a way to stop the debris transportation (Victorian Government, Department of Health, 2010).

This first chapter will introduce the objectives and background of the research conducted in this thesis.

1.2. Background

Wildfires, called bushfires in Australia, are common events in this country. They are periodical events that damage and change the quality of river water (Williams et al., 2012). The intensity and magnitude of bushfires in Australia, tragically impacts people and communities and caused vast damage to the environment, infrastructure, private property and the community (Victorian Bushfires Royal Commission, 2009).

The natural environment provides many social, economic and environmental benefits for humans (Sparkes, 2015). Fires place many aspects of the environment at risk or in a vulnerable position (Nyman et al., 2011); some flora and fauna species are certainly put at further risk of extinction.

Fortunately, the natural environment is usually very resilient (Bowmer, 2012). Although fire is a natural event in Australia, and the ecosystems recover from fire, being adapted to this type of event, the natural environment needs significant management after the bushfires (Palmer and Munawar, 2009; Bell et al., 2014).

In some areas, the natural environment recovery was evident after a few months, whilist in others it takes years for the flora and fauna to regenerate (Department of Sustainability and Environment, 2012; Lane et al., 2009).

Fire management agencies are often required to construct fire control lines to protect life and property as part of the effort to stop or control the bushfires (Department of Environment and Conservation, 2008). These must be rehabilitated as practically and quickly as possible in order to avoid extreme erosion events. Sometimes rehabilitation occurs whilst fires are still burning if the resources are used efficiently.

Also trees that were incompletely burnt in the forest can become a danger for people or wild animals. The forest must be cleaned, so these burnt trees must be removed very soon after fires (Department of Sustainability and Environment, 2012).

The land alongside waterways (called riparian land) is critical to river health for soil stability, sediment and nutrient capture, as well as providing food and habitat for aquatic and terrestrial wildlife (Department of Environment, Land, Water and Planning, 2015a).

Recovery of vegetation along stream frontages following bushfires is crucial because the lack of riparian vegetation means there was little buffer to stop soil and debris from entering into the waterways (Environment Protection Authority, 1998).

After a bushfire, the vegetation and some existent fences are burnt. Fences must be replaced or repaired as soon as possible. This is one of Catchment Management Authorities' responsibilities, helped by private landowners. In this way the stock is kept away from the waterways until the vegetation is recovered after the bushfires (Department of Sustainability and Environment, 2012).

Monitoring water is always important, but it is even more critical after bushfires, when water quality and waterway health are compromised (Nyman et al., 2013). Many water quality parameters have higher values soon after heavy rain following a bushfire. Some of them, such as total nitrogen, total phosphorus and total suspended solids, sometimes exceed the threshold established by legislation. Depending on the land use, land cover and geology of the catchment, there could also be other water quality parameters that must be taken into account after bushfire, such as silicon, heavy metals and pesticides. Also, the ash transported in the river can contain different chemical elements or compounds, depending on the type of burnt forest. For example, calcium carbonate ($CaCO3$) can be found in wood ash as Demeyer et al. (2001) suggested. Iron, manganese, zinc and copper, were found in the pine ash by Ferreira et al. (2005). Khanna et al. (1994) found in eucalypt litter ash: iron, manganese, zinc, copper, aluminum, lead and sulfur.

Monitoring campaigns are very expensive and involve many people and devices (Bartley and Speirs, 2010). Some of the parameters can be measured in-situ (Environment Protection Authority, 2013). This procedure is used for some water quality parameters which can degrade in time, so the samples cannot be kept too long before the analysis. These interact with other chemicals and are influenced by the bio-chemical reactions, so their concentrations change very easily (UNESCO/WHO/UNEP, 1996). Another reason for in-situ measurements is that the procedure of analysis is very easy and it is preferable to do it in the field instead of carrying quantities of water sample to the laboratory.

1.3. Research objectives and questions

Water quality planning responsibilities involve the management of land use change, the detection of the early signs of soil erosion and the reducing of the nutrients and sediment loads from agricultural, forestry and urban land use in order to make wise decisions to improve the river water quality (Victorian Parliament, 1970). This research is designed to develop a spatial approach to support the planning of the water quality in the areas subjected to bushfires, using a case study from Victoria. In particular, this research involves the implementation of a hydrological model in order to predict the river water quality, to assist in the decision-making process.

The objective of this research therefore is to apply a hydrological model, in order to predict the river water quality parameters after bushfires.

The research questions addressed in this thesis are:

1. What information is required to establish the water quality and what are the gaps in existing local water quality databases?
2. Which pollutants are affected by fire and by how much?
3. How can a hydrological model be used to integrate datasets, to provide missing information in existing water quality database?
4. How can we predict future impacts?

1.4. Methodology

The methodology of this research has been based on applying a hydrological model to a selected catchment, in order to predict the river water quality parameters, for different periods of time (with and without bushfires). The Latrobe catchment, situated in West Gippsland, was chosen for this research project because it is a bushfire prone area and the Department of Environment, Land Water and Planning holds a database of the river water quality for this region. The hydrological model applied is *eWater*. The model was run and was calibrated, by finding the best parameterisation for this catchment. Then, the model was validated with measured water quality data. Finally, *eWater* was evaluated, by applying statistical methods for measuring the quantitative and qualitative performance.

Thesis structure

The body of this thesis will be made up of nine chapters.

Chapter 1, the current chapter, introduces the objectives and the background of the research and finally outlines the structure of the thesis.

Chapter 2 presents details about water quality management responsibilities of the different levels of Australian Government.
Chapter 3 covers the literature review divided in two parts: water quality parameters and the water quality models.
Chapter 4 contains the criteria for selecting the pilot study area – Latrobe Valley and its hydrological and related characteristics.
Chapter 5 includes information about the database construction.
Chapter 6 incorporates *eWater*, the hydrological model used to predict the water quality parameters.
Chapter 7 comprises the way in which the model was developed, the validation and evaluation of the model.
Chapter 8 shows an improvement of the model in order to provide water quality parameters with higher accuracy.
Chapter 9 has the conclusions, limitations and further research.

1.5. Conclusions

This chapter introduced the reason for this research project being implemented. Also, the objectives and research questions were established. Then the methodology used was briefly explained. Finally, the thesis structure was stated.

2. WATER GOVERNANCE IN AUSTRALIA

2.1. Introduction

The goal of natural resource management is to improve community welfare through sustainable use and the protection of the natural environment. Maintaining the quality of water resources is an integral part of environmental management and it is essential for the continuing viability of a society (Department of Agriculture and Water Resources, 2016). The general community, therefore, has an important interest in water quantity and quality (Bowmer, 2012; Environment Australia, 2002).

Drinking water and water that supply our basic needs is essential for people, as well as water for agricultural purposes. The focal point of water resources is the volume of water available for particular purposes. Water quality determines the suitability of water for a particular purpose (Food and Agriculture Organization of the United Nations and Earthscan, 2011). Managing water quality requires a catchment-based approach because landuse has a major effect on the quality of water resources. The amount of available fresh clean water is changing because of growing populations, changes in farming and the new needs of industry (Department of Sustainability and Environment, 2011). Water pollution has the potential to become a limiting factor for growth. Pollution may have adverse effects on drinking water supply, on the use of water for the production of food and by other industries, on the environment and on activities such as fishing, recreation and tourism (Honga et al., 2012; Sunlu, 2003).

In order to protect the quality of the water resources, a united effort by land managers, industry, catchment groups, the community, environmental groups and Australian state/territory and local governments is required (Victorian Government, 2008).

Responsibility for environmental management is divided between the Commonwealth, the states and the territories. Several mechanisms are in place to enable the government agencies with responsibility for water and the environment to develop a joint approach to water quality management (The Parliament of Victoria, 1989).

The Water Quality Management Framework includes a step-by-step approach to planning, implementing and managing water quality for a certain area, plus information about common environmental stressors (Victorian Catchment Management Council, 2016).

This chapter details the responsibilities of various authorities at federal, state and local levels about the monitoring, assessment and management of water quality as well as collecting, analysis and delivering information related to this.
The government agencies in Australia, that are involved, are analysed as follow: in the first part of this chapter there is the basic information about how the Federal Government is involved in water quality assessment; the second part is dedicated to the responsibilities of the Victoria State Government, then the local government responsibilities are listed. At the end of this chapter, there are some statutory authorities that are involved in this matter as well as a matrix of authorities and responsibilities, in order to highlight the common responsibilities and the importance of water quality management at various levels.

2.2. Responsibilities for water management in Australia: The Federal Government

Department of the Environment and Energy

The Department of the Environment and Energy (DEE) designs and implements the Australian Government's policies and programs to protect and conserve the environment, water and heritage and promote climate action.
The process for water quality management is based on national guidelines that are implemented at state, regional and local levels. The national water quality guidelines are the basis for development of all State and local plans and objectives.
The National Water Quality Management Strategy, (Department of Agriculture and Water Resources, 2016) incorporates:

> *"a. national consistency in methods for setting goals, objectives and standards;*
> *b. clear and explicit administrative processes;*
> *c. clear and explicit assignment of responsibilities for the various phases of administration and operation;*
> *d. accountability, where progress towards the desired water quality goal is monitored and reported;*
> *e. matching of the administrative structures to the physical and social constraints, commonly on a catchment or sub-catchment basis;*
> *f. involvement of stakeholders in definitions of goals, development of plans and implementation of strategies;*

g. administrative mechanisms responsive to change and development, including changing physical conditions over time, changing public preferences for water quality and resource management, and new technical options;

h. opportunities for harnessing market forces to the water quality management task".

The Australian and New Zealand Environment and Conservation Council (ANZECC) is the peak Ministerial Council for inter-governmental consultation and co-ordination on environmental and nature conservation matters.

The DEE, also known as the Australian Water Resources Council (AWRC) is the peak forum of the water industry for consultation, co-operation and liaison on the development of water industry policy at international, national, and state levels. In 1993 the Agricultural Council of Australia and New Zealand and the Australian Soil Conservation Council had combined to form a new Council, the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (Agriculture and Resource Management Council of Australia and New Zealand, 2001). It comprises Commonwealth, State and Territory Ministers responsible for agriculture, soil conservation and water matters. The National Health and Medical Research Council (NHMRC) is actively involved in areas affecting public health. It consists of representatives of Commonwealth, State and Territory health authorities and medical, nursing, industry, environment and scientific groups as well as a broad spectrum of community representatives. ANZECC, ARMCANZ and NHMRC are working together to develop a coordinated approach to water quality management (Department of Agriculture and Water Resources, 2016).

Water quality guidelines, set by NHMRC, define desirable ranges and maximum levels for certain parameters that can be allowed (based on scientific evidence and judgment) for specific uses of waters or for protection of specific values. They are generally set at a low level of contamination to offer long-term protection of environmental values (Department of Agriculture and Water Resources, 2016).

2.3. The Victorian State Government

At the state level, the approach to water quality management uses water quality planning and policy instruments while taking into account the national goals and obligations to other states and territories. The process can be summarised as (Department of Environment and Primary Industries, 2013):

• a state uses its own water quality planning and environmental policy tools to set water quality objectives and goals, which are in line with the agreed national guidelines.

• regional communities are encouraged to participate on a catchment basis in the identification of local environmental values and the associated water quality criteria.

• local management strategies are developed and implemented.

2.3.1. Department of Environment, Land, Water and Planning (DELWP)

The DELWP portfolio includes over 100 major agencies (e.g. large public entities) and 1,200 small committees of management of Crown Land reserves (Department of Environment, Land, Water and Planning, 2014). DELWP agencies are responsible for managing, regulating and/or advising the Victorian Government in relation to their portfolio area, as set out in their establishing Act or terms of reference. Following the 2014 State Election, the Department of Environment and Primary Industries (DEPI) is now part of the DELWP.

The DELWP's responsibilities begin with catchment and waterway health and extend through infrastructure oversight, water saving and re-use projects, flood management to governance and water legislation. Their approach includes innovative planning, adaptive management, monitoring and regulation, prudent investment, effective policies and on-ground programs.

2.3.2. The Victorian Catchment Management Council (VCMC) is the State Government's key advisory body on catchment management (Victorian Catchment Management Council, 2016). As an independent, expert body, the Council is well placed to influence change in working towards its vision for catchment management in Victoria, taking a statewide, long-term and strategic view (VCMC).

Every five years the Victorian Catchment Management Council is required under the Catchment and Land Protection Act 1994 (The Parliament of Victoria, 1994) to report to Parliament, through the Minister for Environment, on the condition and management of Victoria's land and water resources.

2.4. Local Government

The local government bodies which have various functions related to the water resources and management are:

2.4.1. Municipal Association of Victoria - MAV (Municipal Association of Victoria, 2017) is involved in the development of policies and programs which contribute to best-practice management of water in the urban environment (with key stakeholders including VicWater, the Office of Living Victoria, EPA Victoria, Melbourne Water, universities and the Victorian and Federal Governments).
The MAV is the statutory peak body for local government in Victoria, representing all 79 municipalities.
The MAV has for many years been engaged in Integrated Water Cycle Management (IWCM), both through the Victorian Stormwater Action Program, the Stormwater and Urban Water Conservation Fund, and by establishing the Clearwater Association, which provides IWCM project tools and training for local government and water industry employees. Together these programs have delivered hundreds of stormwater management projects throughout Victoria (Municipal Association of Victoria, 2013).

2.4.2. Councils have as priority issues: managing pollution, litter and storm water quality (Victorian Government, 2014a). The sustainability principle is to minimize the impacts of pollution on the waterways and beaches. The role of Councils is as lead agency and the tools of Council are the strategic plans and local laws (Victorian Government, 2016).
Councils have embarked on a series of actions to improve water quality throughout the municipality. This includes the installation of gross pollutant traps in main drains and by improving road and drain maintenance regimes throughout the municipality.
Councils have also introduced water sensitive urban designs like swale drains and wetland treatments.

2.5. Statutory Authorities

2.5.1. The Environment Protection Authority Victoria (EPA Victoria)

The purpose of The Environment Protection Authority Victoria is to care for and protect the environment. It has the responsibility for strategic direction of the protection of water quality and water quality monitoring (Environment Protection Authority Victoria, 2016a). Within the water industry, the EPA Victoria plays an important role in the regulation of the discharge of wastewater. The EPA Victoria is an independent statutory authority with an independent Chairman. There is also an Advisory Board which is appointed by the Governor-in-Council and comprises three members with scientific, community and business expertise. This Board provides an overview of the administration and policies of the Authority, without direct management responsibility or a regulatory role. It also provides advice to the Chairman and the Minister for Environment and Climate Change on EPA Victoria administration, functions, policies, strategic direction, corporate planning and on national and international trends in environment protection.

2.5.2. Parks Victoria is a statutory authority (Parks Victoria, 2016), created by the Parks Victoria Act 1998 (Parks Victoria, 1998a) and reporting to the Minister. It is responsible for managing an expanding and diverse estate covering more than 4 million hectares, or about 17 per cent, of Victoria. It was created for the protection and enhancement of Victoria's parks and waterways.

Parks Victoria is committed to delivering works on the ground across Victoria's park network to protect and enhance park values. It is its primary responsibility to ensure parks are healthy and resilient for current and future generations. It manages parks in the context of their surrounding landscape and in partnership with Traditional Owners. It works in partnership with other government and non-government organisations and community groups such as the Department of Environment, Land, Water and Planning, catchment management authorities, private land owners, friends groups, volunteers, licensed tour operators, lessees, research institutes and the broader community.

2.5.3. Victorian Environmental Water Holder is an independent body, established in July 2011 to manage the Victoria's environmental water (Victorian Environmental Water Holder, 2010a). Having this responsibility, the VEWH helps to protect the environmental in the wetlands and floodplains from Victoria.

The VEWH collaborates with catchment management authorities and Melbourne Water to use the best practices for environmental water that is available.
The main responsibilities of the VEWH include:

- making decisions on the most effective use of the Water Holdings, including use and trade;
- authorising waterway managers to implement watering decisions;
- liaising with other water holders to ensure coordinated use of all sources of environmental water;
- publicly communicating environmental watering decisions and outcomes;
- commissioning targeted projects to demonstrate ecological outcomes of environmental watering at key sites.

Every year, the key function of the VEWH is to create a seasonal watering plan that prioritizes the watering activities of the entire State in an integrated way. The plan sets the scope for environmental watering activities that could occur under a range of climatic scenarios - from severe drought, right through to an extremely wet year (Victorian Environmental Water Holder, 2016).
As conditions unfold, and water becomes available throughout the year, the VEWH releases seasonal watering statements to communicate decisions on environmental watering activities that are actually to be undertaken (Victorian Environmental Water Holder, 2010b). The statements are a record of the implementation of the seasonal watering plan, and can be made at any time throughout the year. Depending on the nature of the system and the entitlement being used, there may be one or multiple statements made for a particular system. In addition to communicating decisions on environmental watering activities, the seasonal watering statements also authorize a Catchment Management Authority or Melbourne Water to order and deliver water on behalf of the VEWH.
Environmental flows are not the only factor in a healthy river, wetland or floodplain. Also important are other aspects, including water quality, riparian land and in-stream habitat. It is important that environmental watering and complementary measures are integrated to achieve the best environmental outcomes.
Complementary measures can include (Victorian Environmental Water Holder, 2012):

- revegetation of waterways to provide habitat and prevent erosion
- streamside fencing to protect habitat from livestock damage and allow regeneration

- provision of fish passage to allow breeding and recolonisation
- better management of river banks to maintain and improve water quality.

2.5.4. Water corporations

Victoria's state-owned water sector is made up of 19 water corporations constituted under the Water Act 1989 (The Parliament of Victoria, 1989). The water corporations provide a range of water services to customers within their service areas comprising water supply, sewage and trade waste disposal and treatment, water delivery for irrigation and domestic and stock purposes, drainage, and salinity mitigation services (Department of Environment, Land, Water and Planning, 2016).

A number of them also manage bulk water storages and designated recreational areas and help the minister operate the Victorian Water Register.

Sixteen water corporations provide water supply (including recycled water) and sewage and trade waste disposal services to urban customers throughout Victoria (DELWP).

In regional Victoria these are: Barwon Water, Central Highlands Water, Coliban Water, East Gippsland Water, Gippsland Water, Goulburn Valley Water, Grampians Wimmera Mallee Water, Lower Murray Water, North East Water

South Gippsland Water, Wannon Water, Westernport Water, Western Water;

In Melbourne these are:

City West Water, South East Water, Yarra Valley Water;

Four of the water corporations provide rural water services, which comprise water supply, drainage, and salinity mitigation services for irrigation and domestic and stock purposes. These are: Southern Rural Water, Goulburn-Murray Water, Grampians Wimmera Mallee Water, Lower Murray Water.

Southern Rural Water, Goulburn-Murray Water and Grampians Wimmera Mallee Water also provide bulk water supply services to other water corporations in regional Victoria (Water Corporations).

Melbourne Water Corporation provides bulk water and bulk sewerage services to water corporations in the Melbourne metropolitan area and manages rivers, creeks and major drainage systems in the Melbourne, Port Phillip and Westernport regions. It also supplies recycled water, through a number of retail water corporations, for irrigation and other purposes.

The VCMC (Victorian Catchment Management Council, 2016), with the DELWP (Department of Environment, Land, Water and Planning), EPA (Environmental

Protection Authority) and Melbourne Water, undertakes environmental water quality assessment in Victoria (EPA).

It ensures (Environment Protection Authority Victoria, 2015a):

- avoidance of duplication between monitoring programs
- statewide consistency of monitoring methods
- annual reporting that provides interpretation and management information at statewide and catchment management authority scale
- provision of a statewide database of water quality information on the internet.

2.5.5. Catchment Management Authority (CMA)

There are 10 Catchment Management Authorities in Victoria (Victorian Government, 2011), as it can be shown in Figure 2.1.

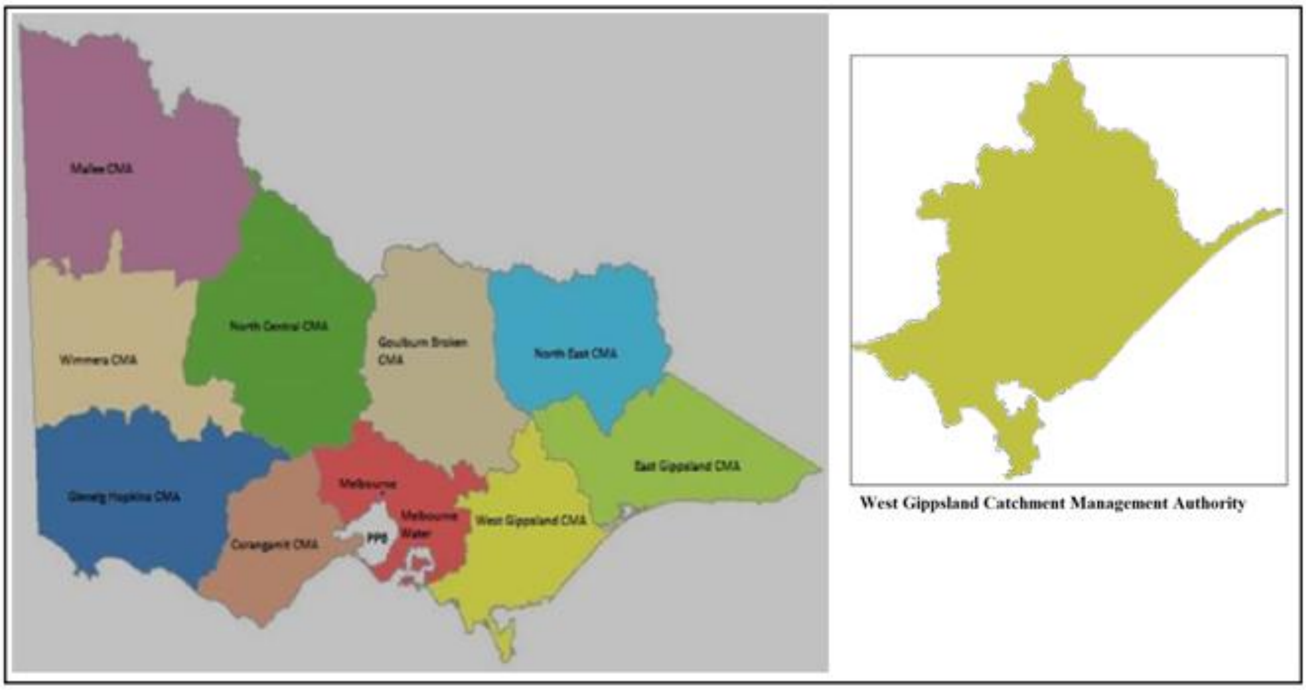


Figure 2.1. Catchment Management Authorities
(Department of Environment, Land, Water and Planning, 2015b)

The West Gippsland Region, legislatively defined by the Catchment and Land Protection Act 1994 (The Parliament of Victoria, 1994), extends from the Gippsland Lakes to west of Warragul, and from the Great Dividing Range to Wilsons Promontory (see Figure 2.2).

Figure 2.2. West Gippsland Region extent (map adapted after West Gippsland Catchment Management Authority, 2014)

The area is 17,685 square kilometres. The West Gippsland population is dispersed between several regional centres in the vicinity of the South Gippsland, Strzelecki, Bass and Princes Highways. The region includes seven municipalities as it is shown in Figure 2.3; all of Latrobe City; substantial parts of Wellington, Baw Baw and South Gippsland Shires; a heavily populated portion of Bass Coast Shire; and small sparsely populated areas of Delatite (Mansfield) and East Gippsland Shires.

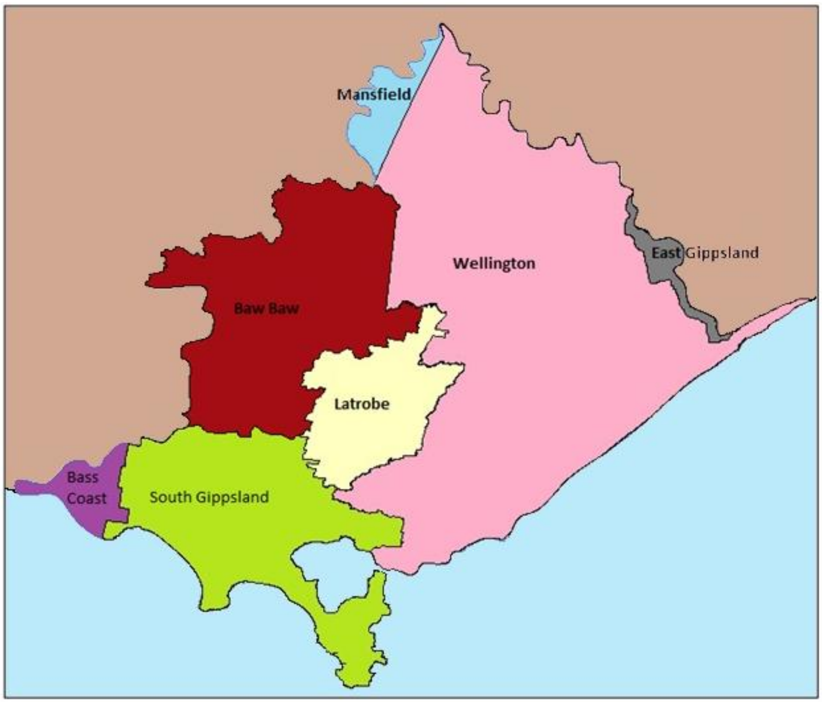


Figure 2.3. The region managed by West Gippsland Catchment Management Authority containing parts of the 7 councils listed above (map created with data from www.land.vic.gov.au)

Regional NRM priorities:
The West Gippsland Catchment Management Authority (Australian Government, 2010) region is subject to a variety of trends that will affect how the natural resource base is managed into the future. These include:

- Social: expanding urban fringe, and ageing of the farming community;
- Economic: intensification of the traditional primary industry base, changing land use, diversification of agribusiness, changing economics and politics of agriculture, and industrial restructure and downsizing
- Environmental: increasing threats from pest plants and animals, increasing demand on water, water quality, water quality monitoring, land subsidence from extractive industries, and climate change influencing weather patterns, sea levels and flooding.

The West Gippsland Catchment Management Authority (West Gippsland Catchment Management Authority, 2016a) has the responsibility to prepare a Strategy for the region and to coordinate and monitor its implementation (West Gippsland Catchment Management Authority, 2016b).

2.6. Conclusion

In the first part of Chapter 2, a brief review of water quality management responsibilities of the Australian Government and other agencies was presented.
In Australia, many of these responsibilities are shared at the all three levels of government and between government bodies and other statutory agencies.
At government levels, some of the tasks are related to the planning of water resources, assessment of water reserve, creating strategic directions and issuing rules and laws for environment and water protection. On the other hand, at all levels of government it is a considerable care for protection of water streams, for preserving the water quality and managing extreme events such as floods or bushfires. Also, the government bodies make decisions for investments and develop public educative programs.
The statutory authorities have duties in water resource management at state and/or local level. Parks Victoria is interested in protecting and managing the water streams inside parks. The water corporations are responsible especially for delivering the water

and are interested in planning and managing the water resources, but also to provide a good quality drinking water.

The local problems, related to the water resources and quality, are solved based on local authorities who are able to know better the issues and the available resources needed.

The published strategic plans related to water planning state that there is a strong link between the government bodies at all levels and the statutory authorities.

Figure 2.4 shows the matrix for water management in Victoria, Australia.

		Federal Government	Victorian State Government	Local Government	EPA	Parks Victoria	Victorian Environmental Water holder	Water Corporations	West Gippsland Catchment Management Authority
	Planning of water resources	■	■	■	■	■	■	■	■
	Assessment of water reserve	■	■	■	■	■	■	■	■
	Development of policies and programs which contribute to best-practice management of water	■	■	■	■	■	■	■	■
	Water supply							■	
	Water quality	■	■	■	■	■	■	■	■
	Water quality monitoring				■	■	■	■	■
	Drinking water legislation	■	■	■	■				
	Protection the water quality	■	■	■	■	■	■	■	■
	Prioritizing the watering activities					■	■		■
	Protect water streams	■	■	■	■	■	■	■	■
	Re-vegetation of waterways					■	■		■
	Stream side fencing					■	■		■
	Flood management	■	■	■	■	■	■	■	■
	Managing pollution	■	■	■	■	■	■	■	■
	Advice for strategic directions	■	■	■	■	■	■	■	■
	Creating strategic plans	■	■	■	■	■	■	■	■
	Managing recycled water	■	■	■	■	■	■	■	■
	Investment	■	■	■				■	
	Developing public education programs	■	■	■	■	■			■
	Issuing laws in water quality and resources	■	■	■	■				

Figure 2.4. The responsibilities for water management in Victoria, Australia

3. WATER QUALITY AND SPATIAL MODELING

3.1. Water Quality

3.1.1. Introduction

The existence of water is one of the vital conditions for all living organisms. It is a valuable resource but it is threatened as human populations grow. In the last few decades the demand for water of high quality has increased (Wood et.al., 2015). Water is used for domestic purposes and economic activities. Usually, this leads to deterioration in water quality and quantity that impact the living organisms, but also the availability of water for human consumption (UNEP/WHO, 1996).

It is already known (Water Quality for Ecosystem and Human Health, 2006) that aquatic environments cannot be perceived simply as holding tanks that supply water for human activities. These environments are complex matrices that can be alter by the human activities, leading to malfunctioning and even destruction (Vitousek et al., 1997).

Water is a major component of living organisms (Sharp, 2001). Human body contains about 70% water (National Aeronautics and Space Administration, 2007), and most of the other animals contain same or even greater proportions. Plants have between almost 90 % water (Kramer and Boyer, 1995). The microorganisms normally contain about 90–95 % water. Water is important physiologically, playing an important role in temperature control of organisms (Guyton, 1976). It is a solvent in which gases, minerals, organic nutrients, and metabolic wastes dissolve. The substances which move through the body cells by fluids are composed mostly of water. Water is a reactant in biochemical reactions, being the essential factor in all the body functions (Jackson, 1985).

From the ecological point of view, water is important because it is the medium in which many organisms live. The most important component that controls the distribution of vegetation over the Earth is water. The most abundant vegetation and implicitly the fauna are found in the wet areas, closer by the water bodies (Blackstock, 2001; United State Natural Resources Management and Environment Department, 2003).

The processes in which water is involved, tectonic processes and human activities shape the Earth as we know it (United State National Research Council, 2010).

By erosion, dissolution and deposition, water modifies the earth’s surface. Rain erodes mountains and coastal cliffs (Lu and Godt, 2013). The rivers excavate large canyons.

The glaciers create fjords, lake basins and even modify Earth’s continental shelves (Migon, 2010). The ocean waves or currents erode the islands and the seafloor and carries the sediment to ocean basins (Hyndman and Hyndman, 2006).

Large water bodies exert noticeable control over air temperature of neighboring land masses. For example, the climate near the ocean is milder compared to the continental climate because the ocean water behaves as a buffer (Strahler, 2011).

Water availability had over historical times, attracted human settlement and exploitation of wetlands (Food and Agriculture Organization of the United Nations and Earthscan, 2011). Gradually, humans found methods to use the underground water, to store and convey the water, and to irrigate the crops (Harrington and Cook, 2014). All of these allow humans to disperse, being able to live in areas which previously were dry and uninhabitable. Even today, water availability is a condition for human settlement (Newton et al., 1998).

Water is an important element of industry (Cullen, 2000). It is used for power generation, for cooling, and processing. In processing, water may be used as an ingredient, solvent, or reagent. It also may be used for washing or conveying substances and the waste resulting from processing often are discharged in water (Australian Water and Wastewater Association, 1997).

Water bodies are a very good transport way for passengers and for wares. Much of the world’s commerce depends upon maritime shipping that is relatively inexpensive (Corbett and Winebrake, 2008). Inland waterways also are important in both international and domestic shipping.

Also, there are many types of recreational activities that could be conducted in and around water bodies (Parks Victoria, 1998b).

Land use has a huge influence on river water quality (Fucik et al., 2014). Depending on what activities are developed in the area close by the water stream, some water quality parameters in the stream can have bigger values. For example an agricultural land use can determine the release of immense quantities of nitrogen and phosphorus in the river (Rashid and Romshoo, 2013), but also pesticides and heavy metals (Mossop et al., 2013). The coal mining industry causes the ecological deterioration and the river pollution below the mine (Hobbes et al., 2008). The wastewater from mine determines low levels of electrical conductivity, high acidity and temperature and bigger levels of zinc and nickel compared with the environmental regulations (Belmer at al., 2014; Wright, 2012).

There are some studies that show that increasing urban land use has impacts on the environment and especially on water quantity, on the long term (Gainsborough, 2002). Urban expanse possibly increases the flood risk within the urban system. To solve this problem is usually very expensive. The impact of urbanization on the environment and water quantity and quality depend on the land use area, but also on the distribution and spatial patterns of the land (Nuissl et al., 2008, Burchell and Mukherji, 2003)

Also, the open land, without vegetation, leads to an increased direct runoff into the river water, and to a pour filtering and retention capacity of the soils for pollutants (Deal and Schunk, 2004).

The impact of bushfires on water quality can vary greatly, depending on the magnitude, intensity and extent of fire, meteorological conditions and the land use (Heath et al., 2011; Nyman at al., 2011; Bartley and Speirs, 2010). A high magnitude and intensity bushfire produces big quantities of ash and nutrients on a large area (Bodi et al., 2014). Also, the hydrophysical properties of soil change after a fire (Yusiharni and Gilkes, 2012). Meteorological factors, especially rain, highly impact the river water quality. High magnitude rainfall events soon after fire generate runoff and huge quantities of ash, nutrients and contaminants are carried into streams (Rulli and Rosso, 2007). The water quality is impaired and the period of time that the watershed needs to recover depends on a variety of factors (Horwitz and Sommer, 2005; Earl and Blinn, 2000).

Water quality assessments in Victoria are based on data from a number of sources. Firstly, EPA site data from water samples taken and field parameters measured at the time of biological sampling (Environment Protection Authority Victoria, 2015a). There are, however, limitations in the use of these data in that it only represents two points in time and trends cannot be described, nor can it be clearly stated whether water quality meets established objectives. These data can only be used to give an indication of the conditions in which the biota was living at the time of collection, and to help explain differences in community composition. The site based water quality data are, in effect, water quality snap-shots of the catchments (Bobbi et al., 2003). These snap-shots can be used to graphically display longitudinal patterns in chemical gradients along the rivers, but should be interpreted cautiously due to the small number of samples and because the snapshot samples are spread out over a period of weeks.

A number of reports and databases exist which assess or provide long-term water quality data throughout the Latrobe, Thomson and Avon catchments (Environment Protection Authority Victoria, 2015b). The major sources used are annual reporting from

the Victorian Water Quality Monitoring Network (Department of Natural Resources and Environment, 1999).
The information from these sources is used in conjunction with the water quality data collected during the biological sampling to complement and strengthen the understanding of environmental quality in the rivers and streams throughout the catchments.

3.1.2. The chemical parameters that influence the water quality

Between water quantity and quality is a very strong interconnection, even though, usually, the respective parameters are not measured simultaneously (Howard and Bartram, 2003). To measure water quantity, there are often use remote hydrological monitoring stations which record water level, discharge, and velocity. It is easier to monitor the water quantity, to a certain degree, with a minimal amount of human intervention, once a monitoring station has been set up (Bureau of Meteorology, 2010). On the other hand, to measure some parameters that characterize water quality, the samples must be collected and then analyzed in a laboratory environment. It is necessary the human intervention and the costs associated with these actions could be sometimes very high. This is a reason that only a few water quantity parameters are measured, in certain periods of time. Water quality monitoring is vital in the management of water, especially after bushfires (Minshall et al., 2001).
The quantity and quality of water are influenced by natural and anthropogenic elements (Bartram and Balance, 1996). The natural causes that impact the water could be: hydrologic factors that could lead to runoff, atmospheric processes like the transport of pollutants by wind, then dry and wet deposition, and biological processes within the aquatic system. All of these could alter the physical and chemical properties of water. This is the reason that water contains different dissolved and non-dissolved substances. Many of them are essential components that help maintain the health of the living organisms in the ecosystem (Stark et al., 2000).
Land use is perhaps the most important anthropogenic factor affecting the Earth’s surface (Lambin et al., 2001).

Natural water may also contain living organisms that are integral components of the biogeochemical cycles in aquatic ecosystems (Likens et al., 1981). Some of these can be harmful to humans if are presented in drinking water.

The capacity of the aquatic systems to preserve the health of their ecosystems is influenced by the quantity and quality of water (Whittington et al., 2000). If the water quality and quantity are altered, the aquatic organisms suffer and the number of individuals of the different species decline until they are completely lost.

Malmon et al. (2007) stated that the Total Suspended Sediment (TSS) concentration in flood water increased by up to 2 orders of magnitude following a fire. The sediment yields decreased over several months, even years, due to re-vegetation in the catchment.

To prove the importance of land use, in the research made by Bartley and Speirs, (2010) they found very high median TSS concentrations from Mining (~50,000mg/l) and Horticulture (~3000 mg/l); the highest concentrations of TN are from Horticulture (~32,000µg/l) and the bigger concentration of TP it is from Forestry (~5,800 µg/l). Also, they found that the data collected with various methods from forest sites with the same characteristics showed high variability: the TSS values vary from 2 to 95 mg/l, the TN values from 150 to 566 µg/l and the TP values from 14 to 209 µg/l.

To make an assessment of the water quantity and quality, it is necessary to analyse certain physical and chemical indicators. It is important to consider the parameters alone, and also the interactions between contaminants, which may affect the living organisms. The type of measurements is essential; the spot measurements in time do not reflect the real situation. Sometimes, the appropriate parameters are not measured and the data is not very reliable to be used for the assessment and then for water management.

There are two approaches when one analyzes water pollution, depending on the type of pollution source: point sources and nonpoint sources.

When the wastewater is discharged through a pipe, this point is a water pollution point source, (industrial operations or urban wastewater).

The discharge in a stream, after storm runoff, accumulates pollutants from a broad area, being considered a nonpoint source. The area can include farmland, industrial, urban or construction sites. The wet and dry deposition can be also considered as nonpoint source of pollution.

The properties of water pollutants vary widely. The decay of organic compound demands oxygen. The products of decomposition are the major contaminants in river water. Other important pollutants are the suspended particles, which can create turbidity, water becoming unaesthetic. Solids can settle, creating sediment deposits that reduce the water depth, and shallow water stimulates the aquatic macrophyte breeding that leads to water infestation. In shallow water, the oxygen demand for organic compound decay can cause anaerobic conditions. The suspended solids can be highly organic when they come from industrial or urban wastewater, or could have high proportion of inorganic, if they come from agriculture or construction sites.

Urban wastewater, runoff from residential areas, from cropland and pastureland, contains high levels of nitrogen and phosphorus.

Toxic substances, discharged in the streams, from industrial or agricultural landuse may have adverse effects for the aquatic organisms. Even if the water is treated before use, the toxins cannot be removed and they can be hazardous for domestic drinking water or for agricultural irrigation.

A known source of acidification in natural waters is the runoff from mining areas. Also, the pollutants resulted from fuels burning are release into atmosphere and following dry and wet depositions, get into water, increasing its acidity. Another important source of acidification is the rainfall in very populated areas. A major concern in many developing countries is the contamination of waters with various organisms of human origin that produce epidemic diseases to humans.

Sparse but very dangerous source of pollution in natural waters are the accidents that may result in sudden spills of chemical substances, some of them very toxic.

There are hundreds of water quality variables, but the most important physical and chemical indicators usually considered in a basic water quality analysis are nutrients (phosphorus and nitrogen), turbidity, salinity, pH, temperature and dissolved oxygen.

The following nutrients in river water are essential for the biological growth:

1. Total Nitrogen (TN) represents 78.08% by the volume of the atmosphere, but is also a very important constituent of protein in organic matter. However, high levels of nitrogen gas in water can cause gas bubble trauma in fish.

The amino acids are the basic units for proteins. The plants and some microorganisms are capable of converting nitrogen gas to ammonia; they also transform nitrogen into amino acids.

Organically-bound nitrogen is converted to ammonia nitrogen during decomposition of organic matter. Ammonia can be oxidized to a variety of nitrogen species. These reactions are mostly microbial transformations that have a great influence on the forms and concentrations of nitrogen in water (Boyd and Tucker, 2014).

The nitrogen cycle is a global cycle, although most of the components of this cycle function in much smaller systems (Figure 3.1). This cycle can happen even in an aquarium.

The plants fix the nitrogen from atmosphere. The plants are the food required by animals. Fecal material of animals and dead plants and animals become a pool of organic matter that is decomposed by bacteria and other organisms of decay. Ammonia released by decomposition of organic matter and by animals is oxidized to nitrate by nitrifying bacteria, and nitrate is reduced to nitrogen gas and returned to the atmosphere (Eaton et al., 2005).

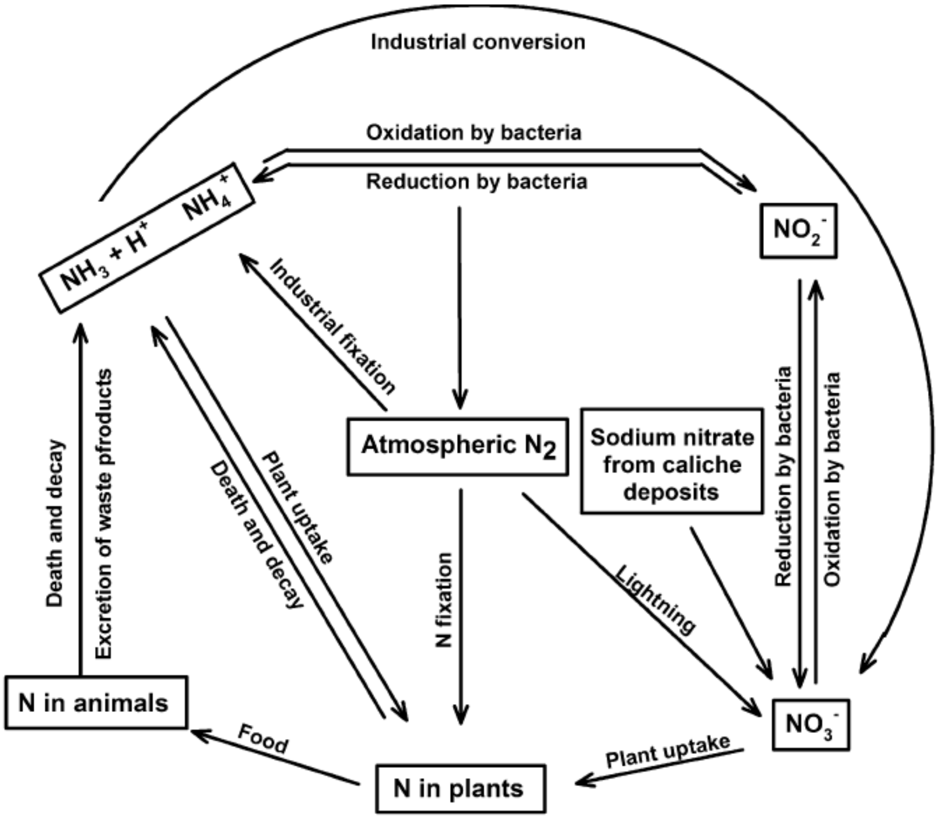


Figure 3.1. The nitrogen cycle (Boyd, 2015)

Most nitrogen transformations are bio-chemical reactions, but gaseous forms of nitrogen can be freely exchanged between air and water.

Nitrogen is not highly reactive and it is soluble in water. Some species of blue-green algae and bacteria are able to absorb molecular nitrogen from water, transform it to ammonia, and combine ammonia with intermediate carbohydrate compounds to make amino acids

Bacteria and fungi decompose organic matter: a part of the nitrogen in organic matter is converted to organic nitrogen and other part is released to the environment mainly in the form of ammonia, a process called mineralization of nitrogen (Boyd and McNevin, 2015).

In a substrate with high levels of nitrogen, the rate of decomposition and the organic nitrogen mineralized tend to increase, so there is more than enough nitrogen to sustain the microbial biomass that develops during decay. But high nitrogen content will not assure that an organic residue will quickly decompose.

When the levels of nitrogen are low, decomposition is slow and microorganisms must die so that their nitrogen can be mineralized and used again to decompose substrate. Also, ammonia nitrogen and nitrate in the environment can be removed and used by microorganisms to decompose the nitrogen-deficient residue (nitrogen immobilization) and it results in a decrease in concentrations of ammonia nitrogen and nitrate in the zone where decomposition is occurring. Where nitrogen is available for immobilization, decomposition of low-nitrogen content residues often is greatly accelerated.

In aquaculture, fertilizers that contain nitrogen and phosphorus are used to increase the phytoplankton productivity and to support the fish production. Sometimes, the addition of nitrogen to water bodies contributes to increase the phytoplankton, leading to eutrophication.

High levels of ammonia in the water make difficult for organisms to excrete ammonia. This means that the concentration of ammonia in the blood of the aquatic animals increases, leading to certain diseases (Hoorman and Islam, 2010).

The ratio of ammonia to total ammonia nitrogen varies with pH and temperature, so the concentration of ammonia in water bodies varies daily. Because the potential for toxicity of ammonia nitrogen concentration depends on several factors such as: pH, temperature, salinity, calcium, chloride, it is almost impossible to establish the lethal concentrations for nitrogen in water bodies.

2. Total Phosphorus (TP) is an extremely important element for all living organisms. It is contained in Deoxyribonucleic acid (DNA) that contains the genetic code needs phosphorus

Phosphorus is also an important component of ribonucleic acid (RNA) that provides the information needed for protein synthesis in organism.

Phosphorus is incorporated into plants, so it is required in relatively large amounts by plants. It is generally the most important nutrient controlling plant growth. Phosphorus concentrations typically are low in natural waters, so the phosphorus pollution of natural waters is considered the primary cause of eutrophication, which means excessive phytoplankton productivity (Mainstone and Parr, 2002). It leads to the decrease of the dissolved oxygen levels in the water that may cause the death of aquatic species, especially the sensitive species, and the overgrowth of algae, resulting in unsightly water and an unpleasant odor (Eaton et al., 2005).

The bottom sediment strongly absorbs phosphorus that is transformed in minerals and the plant growth in aquatic ecosystem requires a continuous input of phosphorus.

Phosphorus has many uses: in agriculture, processing of food, manufacturing of beverages, other industries, and the home. In agriculture the phosphorus is used as phosphate fertilizers, some pesticides and fertilizers (Boyd and Tucker, 2014).

High levels of phosphorus in natural waters are considered a form of water pollution.

Figure 3.2 depicts the phosphorus cycle in an aquatic ecosystem. Plants absorb the dissolved inorganic phosphorus, incorporating it into their biomass. Animals ingest the plants and so phosphorus is passed on to animals. When plants and animals die, microbial activity mineralizes the phosphorus from their bodies. The inorganic phosphorus that is not absorbed by plants is strongly adsorbed by sediment. In the unpolluted waters, there is equilibrium between phosphorus inputs, outputs and storage. Breaking this equilibrium can cause harmful changes in aquatic systems (Boyd and McNevin, 2015).

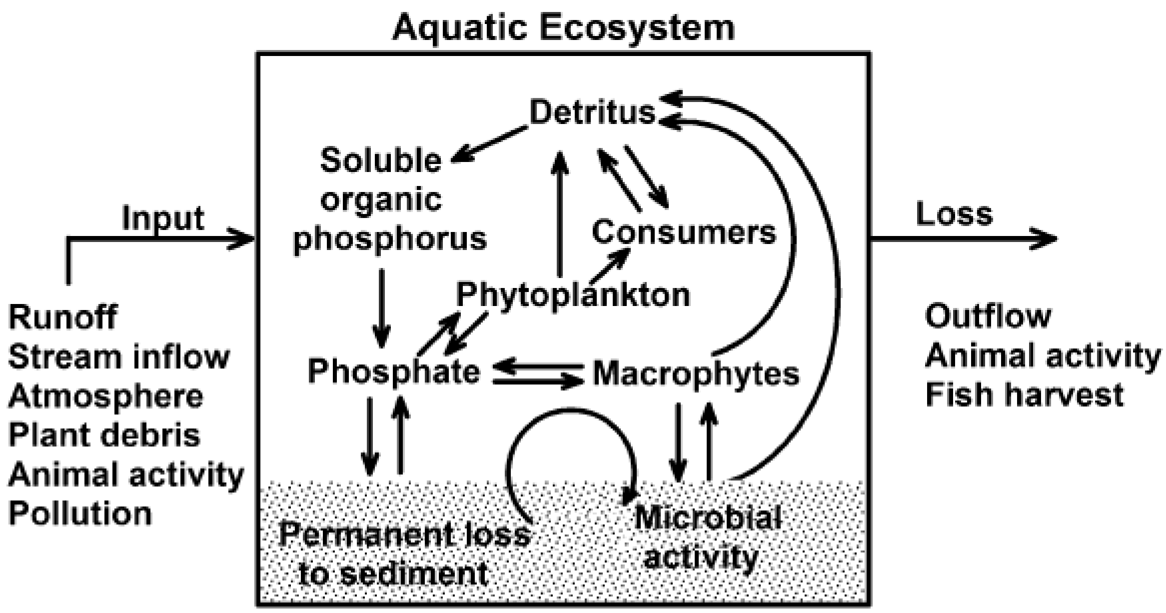


Figure 3.2. A qualitative model of the phosphorus cycle in an aquatic ecosystem (Boyd, 2015)

Phosphorus and nitrogen contained in organic matter are mineralized by microbial activity in the same manner, and in the same conditions. If there is too little phosphorus in organic matter to satisfy microbial requirements, phosphorus can be immobilized from the environment. The nitrogen/phosphorus ratio in organic matters varies noticeable from around 5/1 to 20/1 (Boyd, 2015).

Many studies found relationships between land use and water-quality parameters, such as total dissolved salts (TDS), suspended solids, and nutrient levels (Lindell et al., 2010; Reimann, 2009; Bhat, 2006; Ahearn, 2005). A number of investigations concluded that agricultural land use has significant impact on phosphorus, nitrogen and sediment load (Jiang et al., 2014; Li and Zhang, 2010; Orioli et al., 2008; Ahearn, 2005), in river water.

Phosphorus usually is the most important nutrient that influences the phytoplankton productivity in both aquatic and terrestrial ecosystems.

3*. *pH (the negative logarithm of the hydrogen ion) is a very important water quality parameter is the, because the hydrogen ion influences many reactions in the water bodies.

Because the atmosphere contains large quantities of carbon dioxide, a gas that is soluble in water, rainwater has an acidity of about pH 5.6. The total concentration of titratable bases (bicarbonate and carbonate), expressed in milligrams per liter of calcium carbonate is the total alkalinity, that is less than 50 mg/L in waters of humid

areas with highly leached soils, but it is greater where soils are more fertile, limestone formations are present, or the climate is arid.
The best pH range for most aquatic organisms is between 6.5 and 8.5, the acid lethal point for aquatic organisms is about pH 4, and the alkaline death points are around pH 11. The aquatic animals avoid high carbon dioxide concentration, but they could be able to survive if there is plenty of dissolved oxygen (Boyd and Tucker, 2011).

4. Dissolved Oxygen (DO) concentrations in water depend on the diffusion of oxygen from air to water and backward until the natural waters reach the equilibrium or saturation (United Nations Environment Programme, 2006). The biological activity in the water body changes the dissolved oxygen concentrations faster than diffusion can keep the equilibrium. The photosynthesis by green plants and the respiration by the aquatic organisms are the biological processes that influence dissolved oxygen (Boyd and Tucker, 2014).
During daylight, the photosynthesis usually occurs more rapidly than respiration, so, the dissolved oxygen level increase. At night, photosynthesis stops and the dissolved oxygen concentrations decrease because the aquatic organisms use oxygen. Dissolved oxygen concentration also tends to decline with water depth because the illumination decreases in deeper waters (Boyd, 2015).

5. Salinity means the total concentration of all ions in water. Salinity is estimated indirectly, but it can be determined more accurately from a complete analysis of water by adding the concentrations of all ions. Between the salinity and the density of water is a direct proportional relationship (Boyd and McNevin, 2015).
There are some devices available to measure the salinity of water. The commercial hydrometers that can be calibrated for different salinity can be used to obtain a direct estimate of salinity. The refractometer can be calibrated for salinity concentration, taking into account the fact that the levels of dissolved ions in water are in direct proportional relationship with the refractive index (Boyd, 2015).

6. Total suspended solids (TSS) come in water bodies after erosion by rain and overland flow.
They are very different in size and density. Sand and coarse silt, which are the largest and densest particles, tend to settle to the bottom (gravitational settlement). The fine silt

and suspended clay particles create turbidity in the water body, because they are not enough heavy to settle and the water appears muddy (Eaton at al., 2005).
The total amount of suspended organic matter in unpolluted waters is usually less than 5 mg/L, but water bodies with abundant plankton, the levels of suspended organic particles may reach more than 50 mg/L (Boyd, 2015).

7. Turbidity and light penetration

Most of the solar radiation reaching the earth is in the form of ultraviolet (UV), visible and infrared (IR) rays. Water absorbs visible light depending on its transparency; it absorbs infrared light until 2 m dept and scatters ultraviolet light (Boyd, 2015).
Natural waters contain substances that interfere with light penetration. Phytoplankton, dissolved organic matter such as humic and fulvic acids, or inorganic particles, absorb light at various wavelengths. Dissolved salts in water bodies do not impact with light penetration.
When the sky is blue, the large bodies of water also appear blue, because they reflect the color of the sky. Actually, unabsorbed light rays remaining from the original light give the true color of natural water. The blue and green light from the visible spectrum are scattered back, so this gives a blue-green color to the water bodies. Sometimes, the color of water bodies is different because of the dissolved or suspended particles that absorb light (Boyd and Tucker, 2014).
Waters with a high turbidity are warmer compared to the clear waters in similar conditions. This happens because the turbid waters contain more particles that absorb a bigger quantity of light energy.
To make an assessment of the transparency of water, the Secchi disk can be used. It is a 20-cm diameter disk painted with alternate black and white quadrants (Figure 3.3). The depth to which this disk is visible in the water is the Secchi disk visibility (Boyd, 2015).

Figure 3.3. Secchi disk (The Encyclopedia of Earth, 2014)

Temperature influences the biological activity and growth (United Nations Environment Programme, 2006); up to a certain level, the higher the water temperature, the greater is the biological activity. Temperature also governs the types of organisms that can grow in water. The most evident reason for temperature change in river water is the change in seasonal air temperature. Daily variation also may occur, especially in the surface layers, which are warmed during the day and cooled at night (Boyd, 2015). Some limits for the common water quality parameters were established by the Victorian Government based on the Environment Protection Act 1970. They can be seen in the Table 3.1.

		Forest (mg/l)	Mixed forest and agriculture (mg/l)	Agriculture (mg/l)	Industry (mg/l)	Crops (mg/l)
TSS	**50th** percentile	<5	<10	<20	<50	<60
TSS	**90th** percentile	<10	<20	<40	<90	<100
TN	**50th** percentile	<0.6	<0.7	<0.8	<0.9	<1.0
TN	**90th** percentile	<1.0	<1.2	<1.4	<1.6	<1.8
TP	**50th** percentile	<0.015	<0.025	<0.040	<0.060	<0.070
TP	**90th** percentile	<0.030	<0.045	<0.065	<0.100	<0.120

Table 3.1. Drawn after the In-stream Water Quality Indicators (Victorian Government, 1996) Variation of the State environment protection policy (Waters of Victoria) - insertion of Schedule 5, Waters of the Latrobe and Thomson River Basins and Merriman Creek Catchment, Order Issued by the Victorian Government based on the Environment Protection Act 1970, published in the Victorian Government Gazette, October 1996

3.1.3. The change in concentrations of water chemical parameters after bushfires

Each year, bushfires burn large areas of forest land around the world, particularly in western North America, south-eastern Australia, and the Mediterranean (Food and Agriculture Organization of the United Nations, 2010). In Australia, the bushfires are natural phenomenon that occurs in particularly dry weather.

They are periodical events that damage and change the quality of river water. The magnitude and intensity of the bushfires in Australia, tragically impacted families and communities and caused significant damage to the environment, community infrastructure and private property.

The natural environment provides many social, economic and environmental benefits for humans. Fires put many aspects of the environment at risk or in a vulnerable position (Sheridan et al., 2008).

Extended drought has increased the frequency and scale of fire; severe follow-up storms have resulted in large quantities of sediment, nutrients, organic matter, ash and metal contaminants entering streams and reservoirs.

The impact of bushfires on water quality can be highly variable for many of the individual water quality constituents (Smith et al., 2011a; Smith et al., 2011b). This variability is caused by a number of landscape influences (Foley et al., 2005; Langner et al., 2007) and climatic factors (King et al., 2013), most notably rainfall. High magnitude and intensity rainfall events soon after fire generate large impacts on water quality and sometimes trigger extreme erosion events (Smith et al., 2011a; Smith et al., 2011b).

Combustion of organic matter, soil heating and the production of ash and charcoal contribute to the release of numerous nutrients, metals and toxins that might otherwise be unavailable for transport into waterways.

For some of the water quality parameters there is very little information available, which makes it difficult to draw conclusions about bushfire impacts (Smith et al., 2011a). The constituents of most concern following fire from a drinking water perspective are elevated levels of suspended sediment, nutrients and metals, while possible blooms of cyanobacteria after fire also present a threat (White et al., 2006).

A number of processes can cause water quality impacts following fire as it can be seen in Figure 3.4.

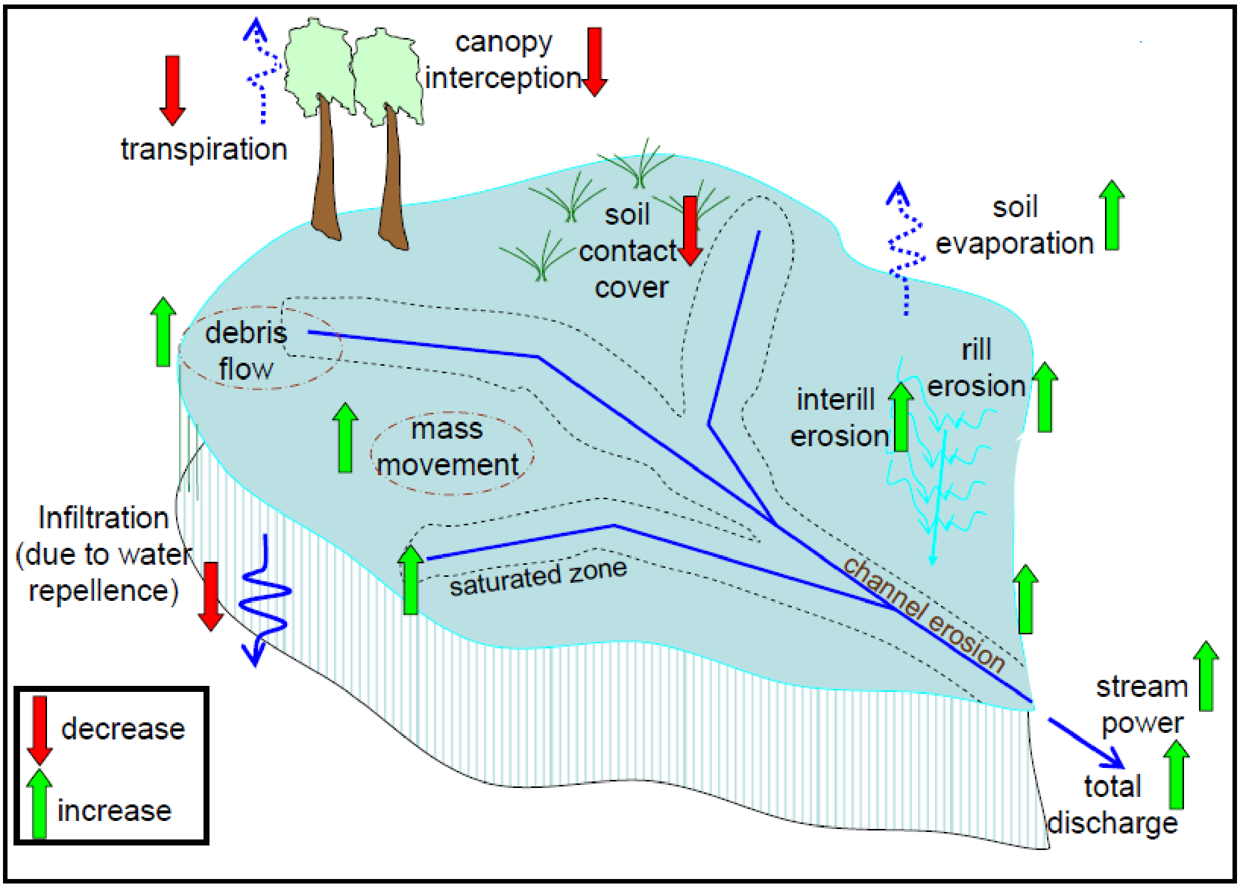


Figure 3.4. Schematic diagram showing possible post-fire changes in hydrologic and erosion processes (Smith et.al., 2011a)

Since the mid-1970s, droughts have increased in frequency and were followed up by bushfires and heavy rain (Steffen, 2015). There are many factors that impact the water quality after bushfires.

The loss of vegetation and the burning soil increase the soil water repellence, leading to runoff and erosion (Cerda and Doerr, 2005). The storms transport big quantities of ash, organic matter and nutrients towards water bodies. All this substances affect the water properties, becoming unfit for use (White et al., 2006; Smith et al., 2011c).

The combustion of organic matter generate ash and charcoal which contains nutrients (nitrogen, phosphorus), particulate carbon, metals and many other chemical substances (Amiro et al., 1996; Goforth et al., 2005; Johansen et al., 2003). The riparian vegetation acts as a buffer for the water body, reducing the quantity of sediment that would be transported into stream. The loss of vegetation increases the load in the water body, affecting the water quality.

The impact of bushfires on water quality is different for various water quality parameters (Smith et al., 2011c).

There is very little information about the most of the water quality parameters, being very difficult to make an assessment about the bushfire impacts on water quality.
From the drinking water perspective, the most concerned water quality parameters are: suspended sediment, nutrients and metals. The greatest threat for the aquatic organisms is related to the high turbidities, low dissolved oxygen concentrations, increase of water temperature and the inputs of nutrients, after bushfires.
For recreation within and around water bodies, cyanobacteria are of most concern, being a potential health risk. Also, the high levels of suspended sediment affect the clarity of water, decreasing the aesthetic values of it.
For agriculture, the biggest concern after fires is related to the high levels of suspended sediments, nutrients, metals, cyanobacteria, chloride and sulfate.
The rate of runoff and erosion is influenced by many factors such as rainfall intensity and duration, soil properties and slope, vegetation cover (Moody et al., 2008; Moody et al., 2005; Martin and Moody, 2001). The magnitude and distribution of rainfall soon after fire, and until the vegetation recovers, is an important factor in erosion processes and water quality.
Bushfires change the levels of chemical constituents in soils and the storms transport them into waterways. The ash deposited after fire contains particulate carbon, salts (especially calcium (Demeyer et al., 2001), magnesium, chloride (Khanna et al., 1994), sulfate, bicarbonate), iron (Demeyer et al., 2001), nutrients (nitrogen and phosphorous), trace metals, mercury, cadmium and arsenic (Someshwar, 1996) and other contaminants (Amiro et al., 1996; Goforth et al., 2005; Johansen et al., 2003). The composition of ash is highly variable and depends on the type of vegetation burnt, the part of the plant burnt, climate, soil type, and combustion conditions (Someshwar, 1996; Demeyer et al., 2001).
The quantities of manganese combined with organic matter increase in soils following fire (Chambers and Attiwill, 1994; Parra et al., 1996; Raison, 1979). A similar draw happened for iron, copper, and zinc (Certini, 2005) and for the sulfate concentrations in surface soils, from burnt plant litter (Khanna et al., 1994; Murphy et al., 2006).
The highest suspended sediment concentrations in streams after fires generally occurred after erosion events, generated by intense summer storms (Lane et al., 2006; Leak et al., 2003; Murray-Darling Basin Commission, 2007; Smith et al., 2011c).
Dissolved oxygen concentrations in streams and reservoirs decrease after fire, as Lyon and O'Connor (2008) reported.

Relatively high levels of polycyclic aromatic hydrocarbons (PAHs) after fire were reported by Kim et al. (2003) in Korea, one month after bushfires. The same situation was noticed by Olivella et al. (2006) in Spain, one month after fires.
Polychlorinated dibenzo-ρ-dioxins, dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs) concentrations in sediments were studied following forest fires in northern Alberta, Canada (Gabos et al., 2001). They found very low concentrations of both PCDD/Fs and PCBs that were compatible with sites background levels. On the contrary, Kim et al. (2003) reported increased PCDD/Fs in burnt forest soils in Korea, one month after fire. The short-term increase was associated with the PCDD/Fs from ash, which was next removed by wind and runoff.
Crouch et al. (2006) found the post-fire water quality parameters between 2 and 6 times higher compared to the water quality parameters before fire: for Total Phosphorus (TP) 5.9 mg/l; for Total Ammonia between 0.005 and 0.28 mg/l; for Total Cyanide about 72 µg/l and for Total Calcium 380 mg/l.
In the EPA report (Environment Protection Authority, 2008), the dissolved oxygen was found in some cases 3 times lower after bushfires compared with the values before fire, the lowest value being less than 1 mg/l.
On the other hand, the EPA Victoria Guidelines (Environment Protection Authority Victoria, 2011) set for some water quality parameters for surface waters the TP value of 0.1 mg/l, for TN a value of 1.5 mg/l, for turbidity 18 NTU and for pH values between 6.9 and 8.3.
The Water Warehouse data show in some locations that the turbidity increases from 15.2 NTU before fire to 60 NTU after fire. Also, the TN values vary from 0.167 mg/l before fire to 2.8 mg/l after fire (Water Warehouse, 2017), so there are some water quality parameters with values higher than the values set by EPA.

3.1.4. The decay of water quality parameters in time and space

Aquatic ecosystems have various inputs and outputs of nitrogen (Sutton et al., 2011). The inputs are rainfall, inflowing water containing nitrogen from natural sources and pollution, nitrogen added intentionally (as in aquaculture), and nitrogen fixation. The outputs are outflowing water, harvest of aquatic products, intentional withdrawal of water, seepage, diffusion of ammonia into the atmosphere, and denitrification. The relative importance of each gain and loss varies greatly from one body of water to another (Lavelle et al., 2005). Nitrogen is stored in aquatic ecosystems primarily as organic matter in bottom sediments, but smaller amounts are found in the water to include nitrogen gas, nitrate, nitrite, ammonia, and nitrogen in dissolved and particulate organic matter. When nitrogen in organic matter is mineralized, it is subject to the various processes and transformations described above, and it can be lost from the ecosystem. However, there is a tendency for recycling of nitrogen in aquatic ecosystems, and in most, equilibrium among inputs, outputs, and stored nitrogen is reached. Pollution can quickly disrupt this equilibrium and cause higher nitrogen concentrations in the water and sediment (Zhang, 2008).

Phosphate is removed from water by reactions with aluminum, and to a lesser extent, with iron in sediment. In alkaline environments, phosphate is precipitated as calcium phosphate. Aluminum, iron and calcium phosphates are only slightly soluble, and sediments act as sinks for phosphorus.

In anaerobic zones, the solubility of iron phosphates increases. Phosphorus is not toxic at elevated concentration, but along with nitrogen, it can lead to eutrophication.

For the dissolved oxygen (DO) the main sources are the fluxes from the atmosphere, the oxygen produced by the aquatic plants and the denitrification (World Meteorological Organization, 2013). The sinks for DO include oxidation of the organic matter such as carbonaceous and nitrogenous material, the sediment oxygen demand (mg/l/day) and respiration of the aquatic plants (Loucks and Van Beek, 2005). The sources and sinks of N, P and DO are sketched in Figure 3.5.

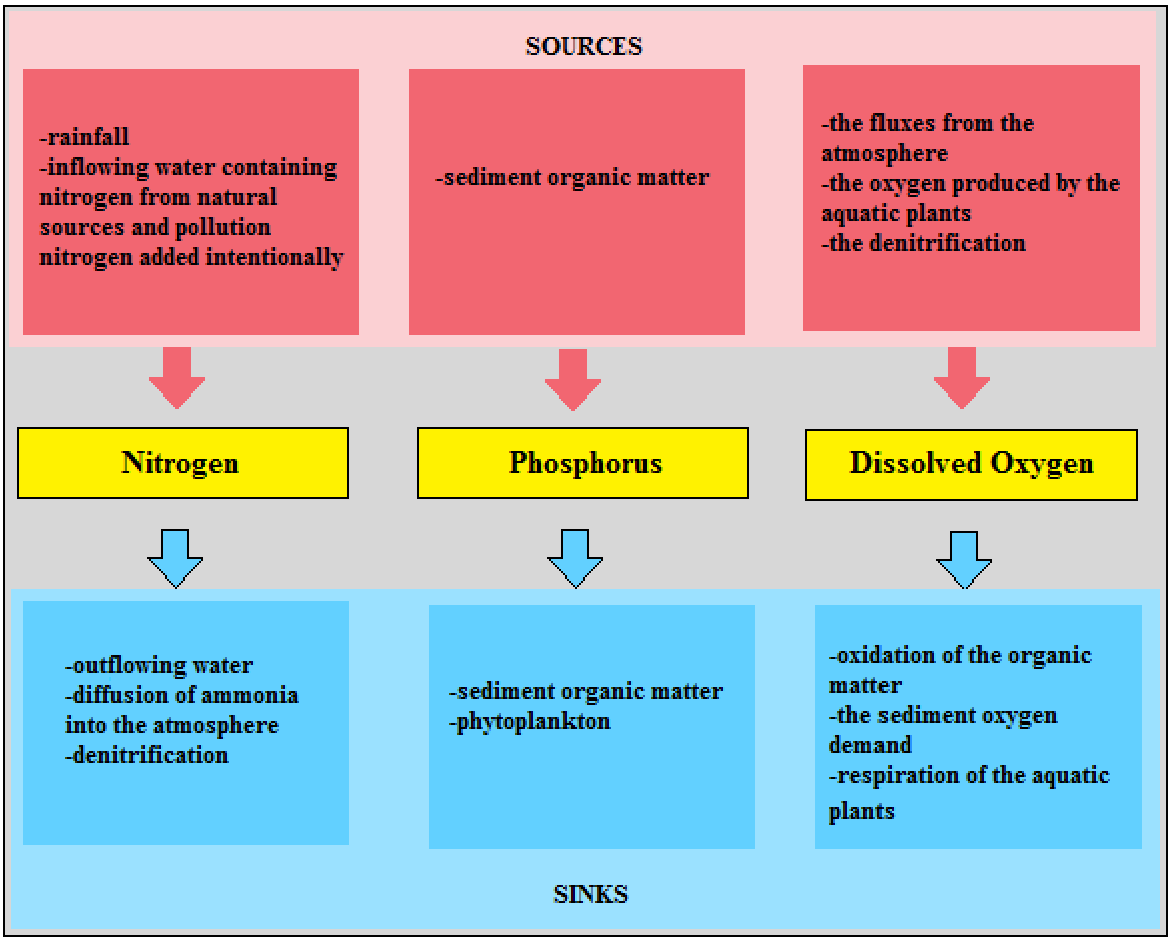


Figure 3.5. Nitrogen (N), phosphorus (P) and Dissolved Oxygen (DO), sources and sinks sketching based on Loucks and Van Beek, (2005)

3.1.5. Conclusions

Availability of freshwater has always been and continues to be an important factor affecting human population. But, as the world's population has grown, water quality has become an equally important issue. Water quality is a critical consideration in domestic, agricultural, and industrial water supply, fisheries and aquaculture production, aquatic recreation, and the health of ecosystems.

Any physical, chemical, or biological property that influences the suitability of water for natural ecological systems or the use by humans is a water quality variable, and the term water quality refers to the suitability of water for a particular purpose. There are literally hundreds of water quality variables, but for a particular purpose, only some variables usually are of interest. Water quality standards have been developed to serve as guidelines for selecting water supplies for various activities or for protecting water bodies from pollution.

The quality of drinking water is a health consideration. Drinking water must not have excessive concentrations of minerals, must be free of toxins, and must not contain disease organisms. People prefer their drinking water to be clear and without bad odor or taste. Water quality standards also are established for bathing and recreational waters and for waters from which shellfish are cultured or captured. Diseases can be spread through contact with contaminated water. Water for livestock does not have to be as high in quality as water for human consumption, but it must not cause sickness or death in animals. Excessive concentrations of minerals in irrigation water have adverse osmotic effects on plants, and irrigation water also must be free of toxic substances. Water for industry also must be of adequate quality.

Extremely high quality water may be needed for some processes, and even boiler feed water must not contain excessive suspended solids or a high concentration of carbonate hardness. Solids can settle in plumbing systems and calcium carbonate can precipitate to form scale. Acidic waters can cause severe corrosion of metal objects with which it comes in contact.

Water quality affects the survival and growth of plants and animals in aquatic ecosystems. Water often deteriorates in quality as a result of its use by humans, and much of the water used for domestic, industrial, or agricultural purpose is discharged into natural bodies of water.

The chemicals created after bushfires are transported in the streams. The ash which resulted after the burnt vegetation contains heavy metals, nutrients such as nitrogen and phosphorus, and many other chemicals depending on the landuse. Also, the runoff increases after bushfire and important quantities of debris is carried into streams. Some of the water quality parameters increase after bushfire between two and six times.

In most countries, attempts are made to maintain the quality of natural waters within suitable limits for fish and other aquatic life. Water quality standards may be recommended for natural bodies of water, and effluents have to meet certain requirements to prevent pollution and adverse effects on the flora and fauna.

3.2. Spatial modeling

3.2.1. Introduction

Hydrological modeling assists in understanding and interpreting hydrological behaviour in a catchment. Hydrological models are also used to address a number of practical issues, ranging from flood estimation to water resources management, water quality or low-flow forecasting. Whatever model is applied, the model user needs appropriate input data depending on the capacity of the model (Shrestha et al., 2006; Mirchi et al., 2009). Model performance can first be evaluated by the visual comparison of the observed and simulated data, but this remains dependent on the researcher's experience (Pushpalatha et al., 2012).

The hydrology of catchments can be complicated (Gentine et al., 2012). Some catchments hold water all year round; others become dry soon after rain; some of them can discharge or can recharge from groundwater. The rate of evapotranspiration is different for every catchment depending on the type of vegetation and the percent of cover (Xu and Yang, 2014). Drainage created by humans can affect the hydrology of wetlands, making it more complex (Moussa et al., 2002). Drainage can directly lower the water levels in wetlands, or indirectly by lowering the water table in the vicinity of the wetland, causing increased infiltration (Brath et al., 2003). Drainage can make the water levels in catchment lower or higher causing changing in infiltration, a process that must take into account when the hydrology of the wetland is modeled.

All hydrological models are simplified characterizations of the real world system (Moradkhani and Sorooshian, 2009). A wide range of models are currently used by researchers, in order to enhance the knowledge and understanding about the hydrological processes that govern a real world system (Peters, 1994). Other types of models are used as tools for simulation and prediction, to help decision makers for management and planning (Mirchi et al., 2009).

The development of hydrological models was based on the availability of data for calibration. These data gives flexibility to the model to extrapolate the hydrological processes for some future periods of time (Pechlivanidis et al., 2011**)**. This view, known as batch model calibration (using batch of data for calibration), has been challenged by another idea, that availability of observation continuously gives the opportunity to the model components (variables and parameters) to be updated sequentially. This is

thought to give more flexibility for taking advantage of the temporal organisation and structure of information content for better agreement of the model output with observed system response (Sorooshian et al., 2009).
In general, hydrological simulation models, which are often named physically-based modeling, use equations that govern the hydrological processes (Arheimer and Olsson, 2001). Furthermore, hydrological data-driven forecasting models, which are often named lead-time forecasting models, are based on a limited knowledge of the modeling process and rely on the data describing input and output characteristics. Performances of hydrological forecasting models are commonly evaluated by comparing forecast and observed outputs (Xu, 2002).
The selection and use of a specific performance criterion and the interpretation of the results are very difficult, since each criterion may place a different emphasis on different types of forecast and observed behaviours, and because the selection of an error measure is dependent on the situation, and not on whether one of the error measures was found to be superior on all criteria (Hwang et al., 2012).

3.2.2. Classification criteria

A basic classification of hydrological models, depending on the various criteria of consideration, can be seen in Figure 3.6, but the available models used in the literature are combinations of these.

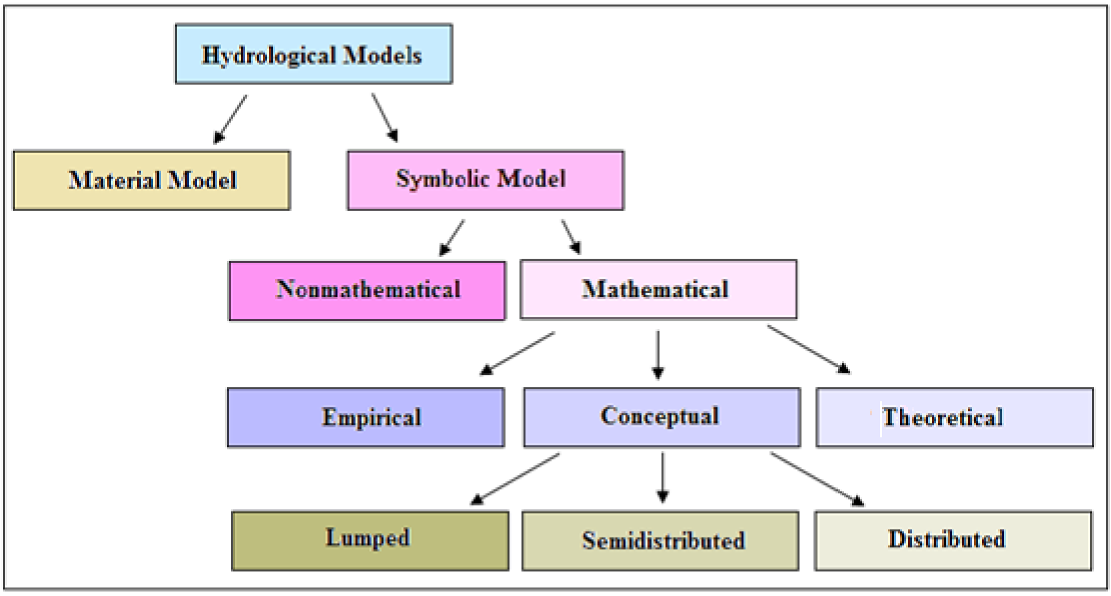


Figure 3.6. A classification of hydrologic models (adapted from Singh, 1988)

A ***material model*** (Xu, 2002; Woolhiser, 1973) is a structure that represents a system with similar properties to a real system, but it is more simplified. Material models can be classified as scale/laboratory models and analog models. The scale model is a reduced scale representation of a real system. Analog models measure different physical properties than the real system. However, there is a strong relationship between the properties of model and real system.

A ***symbolic model*** (Xu, 2002; Woolhiser, 1973) is an expression, in logical terms of a simple and idealized system that have the structural properties of the real system. Symbolic models can be expressed mathematically (using a set of equations) or non-mathematically.

Theoretical models (black-box models) are based on important laws governing the phenomena, and have a logical structure similar to the real-world system. Black box models are purely data based models. They approach the system in terms of input and output with the internal parameters hidden in a black box. Black-box models are based on techniques such as transfer functions, regression, system identification and neural networks (Clarke, 1973; Beven, 2001).

Empirical models (white-box models) can be estimated only by using concurrent measurements of input and output (Sorroshian et al., 2009). They contain parameters that may have little direct physical significance. In many situations, the outputs of empirical models are very accurate, and can be reliable in decision-making. White box models are the opposite of the black boxes. The internal system of the model is fully known. In order to develop a white box, the modeller must know the system in details and sometimes there are too many parameters that must be known to run such model. Usually these models contain representations of real hydrological processes such as surface runoff, evapotranspiration or subsurface flow (Clarke, 1973; Beven, 2001).

Conceptual models (grey-box models) are intermediate between theoretical and empirical models (Kitanidis and Bras, 1980; Duan et al., 1992; Wheater et al., 1993; Abbott and Refsgaard, 1996). Grey box models are placed between white box and black box approaches. The model is not completely described by physical equations,

and the equations and the parameters are physically interpretable (Remesan and Mathew, 2015; Jonsdottir, 2006).
These mathematical models can be useful in different circumstances, depending upon the objective of study, the degree of complexity of the problem, and the degree of accuracy desired. There is no conflict between these models; they represent different levels of approximation of a real situation.
The conceptual and physics based models provide greater accuracy in terms of hydrograph modeling; yet, there are still many issues to be further addressed by researchers (Grayson et al., 1992). Those difficulties include implementation and calibration. The vast amount of calibration data and sophisticated tools are required (Remesan and Mathew, 2015).

Any types of models may be **linear** or **non-linear**. The model can be linear in the system-theory sense (if the output corresponding to input x1(t)+x2(t) is y1(t)+y2(t), given that y1(t), y2(t) are the outputs corresponding to inputs x1(t), x2(t)). This is the sense in which linearity is most widely used in the literature (Xu, 2002). Also, the model can be linear in the statistical regression sense if it is linear in the parameters to be estimated.

A model is **time-invariant** if the relationship between the input and the output is constant over time. Most hydrologic systems are **time-variant** due to variations in physical and chemical parameters during the year.

Another classification of models is per degree of conceptualization of the involving processes: **stochastic** (statistical) and **deterministic** models, according to Figure 3.7.

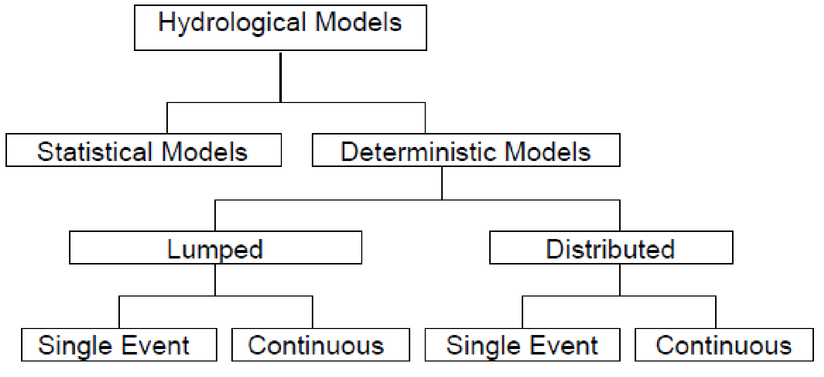


Figure 3.7. A simplified classification of hydrologic models (Bengtson and Padmanabhan, 1999)

Statistical models simulate a random series of numbers with statistical characteristics comparable with real properties, taking into account the uncertainties of the data. Deterministic models simulate the behaviour of the hydrologic mechanisms in a catchment using mathematical equations that describe the different processes of the hydrologic cycle (Singh and Frevert, 2002a; Singh and Frevert 2002b). These models are calibrated by comparing the model output with real data. Models such as the Hydrological Simulation Program – FORTRAN (HSPF) or EPA Storm Water Management Model (SWMM) are considered deterministic models (Bengtson and Padmanabhan, 1999).

However, in most situations, for practical reasons like data availability and calibration issues, researchers choose simple physically based or conceptual models with lumped representation of the system or its parameters. This leads to another classification based on the spatial resolution at which the processes are described as: **lumped, semi-distributed** and **distributed** (Beven, 1985). The first models developed were spatially lumped. They represented the effective response of an entire catchment, without attempting to characterize spatial variability of the response explicitly. The lumping could be a “structural lumping” of the study area or an “empirical lumping” of the dominant processes of interest (Martina and Todini, 2005).

Kadlec (1994) used a lumped model to analyse the hydrological response in a catchment. He considered the wetlands as one single tank or a range of tanks and did not take into account the hydrological processes in the catchments, such as infiltration, evaporation or runoff. Kadlec (1994) calibrated the model using only the outflow of the tank, being close to a black box model.

In distributed models, the hydrological processes are represented with different resolution in space and, in most cases, the model parameters can also be defined as functions of the space and time. In the case of simple representation of lumped models, the hydrological system is represented as a unit block, in which the varying properties are spatially averaged. An example of fully distributed model is AGNPS (**AG**ricultural **N**on**P**oint **S**ource) Model. The model does not divide the catchments in smaller sub-catchments; it divides the catchment in cells with the same size. All the hydrological processes are simulated in every cell and the direction of the runoff is established taking into account the slope (Borah and Bera, 2003).

In semi-distributed models, the whole hydrological system is divided into different blocks, each represented by a lumped model. The choice of a suitable model depends on the availability of data and the goals that are to be attained. An example of semi-distributed model is SWMM - The Storm Water Management Model (Rossman, 2015). Lumped models need less data, the running time is short, but the accuracy of the outputs is low (Beven, 1985). Fully distributed models need more data, have longer running time, but the accuracy is higher (Beven, 1985). Sometimes, there are enough available data for a certain region, to justify the usage of a distributed model. If there are some catchment features that can be modeled by a lumped model, the rainfall-runoff processes must be treated at least by a semi-distributed model.

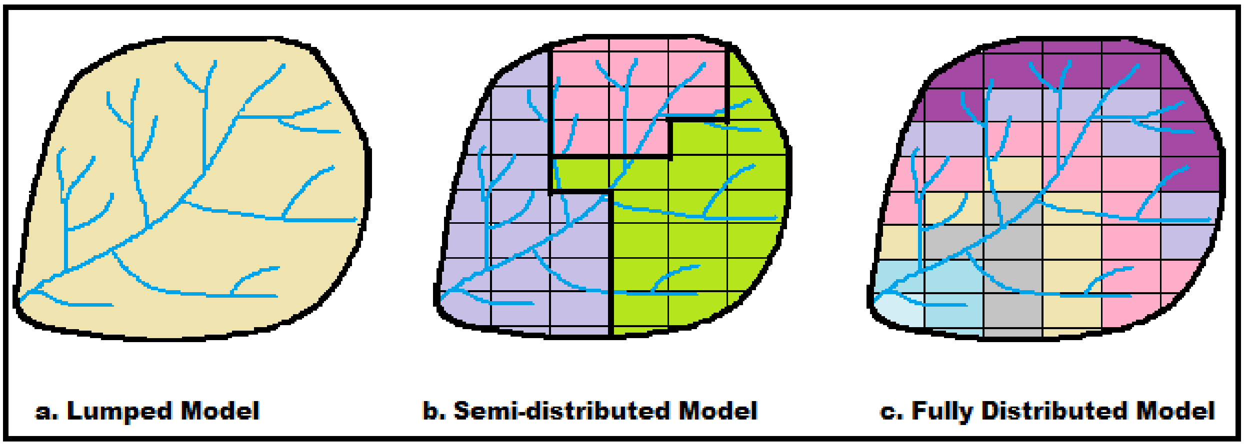


Figure 3.8. Spatial Scaling of Models at sub-basin level
a. Lumped Models: parameters are assigned for the whole sub-basin; b. Semi-distributed Models: parameters are assigned to each grid cell, but cells with same values of parameters are grouped; c. Fully distributed Models: parameters are assigned for each grid cell

Another classification is related to the spatial coverage of the models. They can be **global** or **site-specific**.

3.2.3. Global models

Global Simulation Models (Wilby, 2010) integrate the earth systems, highlighting their interdependence. Climate change (Kundzewicz and Stakhiv, 2010) has an impact at regional and global scale, on soil moisture, terrestrial evapotranspiration (Seneviratne et al., 2010; Dirmeyer, 2011) and river discharge (Milly et al., 2010).

Global hydrology is closely linked with the nutrient cycle (Fekete et al., 2010) and the carbon cycle (causing changes in the climate variability). Land-use changes affect the water quality and quantity thousands of miles downstream.

Also, the global water flow is connected to other systems through physical relationships, systems which can be affected.

Models that attempt to simulate global hydrology and associated processes are similar to hydrological components of the general circulation models (GCMs) (Sood and Smakhtin, 2015). However, they differ in the detail of description of processes, parameter estimation approaches, time scales, and spatial resolution of input data and simulations (Haddeland et al., 2011).

An example of a global model is SimCLIM, an "open-framework" software modeling system that can be used to examine the effects of climate variability in space and time, including the extreme events (CLIMsystems, 2009; Warrick et al., 2012, Warrick, 2009a; Warrick, 2009b; Warrick, 2007; Warrick et al., 2005; Warrick et al., 2001). The model has a personalized GIS and it is able to investigate the impacts of global, regional and local climate on water resources, agriculture or social-economic sectors. The SimCLIM version for Australia, named OzCLIM, was developed by CSIRO (Commonwealth Scientific and Industrial Research Organisation, 2004). Stand-alone models are usually applied at the basin scale, or a smaller catchment scale, and have many parameters that need to be calibrated or estimated. Such models are the Soil and Water Assessment Tool - SWAT (Singh et al., 2014) and the Hydrological Simulation Program- Fortran - HSPF (Banta and Ockerman, 2014).

These are models which can be applied at the global scale, but, due to lack of data, practical it is not possible. The hydrological models that are a part of Global Simulation Models (GSM) are usually land surface schemes (LSSs) that simulate the energy balance at soil, atmosphere and vegetation interfaces at finer time scales (often hours), and do not have a flow routing component. Such kind of models are the Biosphere–Atmosphere Transfer Scheme (BATS), the Integrated Biosphere Simulator - IBIS (Winter and Eltahir, 2011), the Simple Biosphere Model - SiB (Xiao-dong et al., 2010) and the Joint UK Land Environment Simulator - JULES (Best et al., 2011).

Global hydrological models (GHMs) have a few parameters which can be calibrated and are calibrated at regional or large river basin scales (Siqueira Júnior et al., 2015). Some models, such as the Water Balance Model – Water Transport Model - WBM-WTM (Lu et al., 2011), are not calibrated, but they have an adjustment factor to tune them. The model Water – Global Analysis and Prognosis -WaterGAP (Eicker et al., 2014) is a combination of calibration and tuning. It is first calibrated with a single parameter against stream-flow. The basins that underestimate or overestimate flows are then tuned by two adjustment factors, runoff and discharge correction. The spatial resolution of GHMs is defined by the resolution of available global climate input data.

Also, GHMs became more complex and with high resolution as more functionality is added to them and finer global spatial datasets are becoming available.
The explosion of satellite global data availability (Kogan et al., 2011) has had an influence on the development of GHMs. Even if there are some GHMs which were applied at a range of scales, they are built for global-scale studies. GHMs would not be preferred for basin-scale applications, due to their coarser resolution, and to the fact that there is a wide group of hydrological models that have been designed for this purpose. However, GHMs may provide valuable spatial and temporal estimates of global water resources, and help to analyze possible projections/scenarios of changes of those estimates; GHMs have been built effectively for this purpose. Global estimates obtained through GHMs could be an improvement over those simply based on the statistical analysis of ground-based observed data, which, at a global scale, remain limited and, hence, contain a lot of uncertainty (Schellnhuber, 2013). GHMs are also useful when they are linked with other models describing global economy, ecology, trade, biodiversity, energy balance, land-use change, climate change, crop growth and other issues related to water (Nazemi and Wheater, 2015). The requirements from the GHMs depend upon the demands of such associated models. To the best of the authors' knowledge, a single source/compilation of GHMs does not exist.

3.2.4. Site-specific models

Site-specific models are combined models that can be run within a specific area. Physically-based spatially-distributed (PBSD) hydrological models are increasingly used because of their capacity for evaluating the impacts of future climate and land-use changes on river basins (Bovolo et al., 2009; Bekele and Knapp, 2010; Birkinshaw et al., 2011; Shi et al., 2013). One of the major difficulties of these models is the evaluation of the most important parameters to represent a particular basin. Theoretically, these parameters should be accessible from catchment data, but in practice, the cost is too high and there are too many experimental constraints (Zhang et al., 2013).
Since 1990, many models able to utilize distributed information have been developed. These determined the increase of the number of model parameters and the decrease of the confidence in estimating those (Silvestro et al., 2013).

The description of the hydrological cycle is very detailed, so these advanced models have a large number of parameters, which need a detailed knowledge of the catchment to which they are applied (Braud et al., 2010). Some models which describe soil properties and land use have a direct physical meaning. So they can be evaluated using information from various maps of the analyzed catchment, and geophysical cartography utilizing the continuous improvement of satellite-derived information; but not in every situation, the temporal and spatial scales of representation, do match requirements for the reliable estimation of these parameters. Additionally, relationships between land information and model parameters are sometimes indirect and are affected by great uncertainty, so the accuracy of the process description is too low to be taken into account as research findings.

The Stanford Watershed Model, developed by the Stanford University, USA (Borah and Haan, 1990; Haan, 1989; Harpar, 1989; Hromadka and McCuen, 1989; Van Der Schaaf, 1984; Al-Kadhimi Ahmad, 1982; Hudson, 1981; Linsely et al., 1975; Dawdy and O'Donnell, 1965; Crawford and Linsley, 1963) was used to describe the hydrological transport of radioactive elements (Strontium 90) with some success and it was modified to handle the transport of nutrients. The nutrient transport is less suitable for a lumped model because the inputs are not spatially uniform. The transport of nitrogen, as an important nutrient, is quite difficult because nitrogen exists in six major chemical substances, and all of them are included in model. Its hydrologic complexity includes transport and storage of liquid water and the water transformation in solid and gas, and the chemical transformation of the various nitrogen forms. A very important problem is to estimate the initial conditions. The nutrients presented in the soil can be compared to the nutrients added by fertilizer and they will affect the system for long time (Husham et al., 2012; Liou, 1971).

Hydrologic Simulation Program – FORTRAN (HSPF) (United State Geological Survey, 2016) was developed by USA. HSPF was initially developed as a general hydrologic model; later the model was modified and now is most commonly used for water quality studies (Karmakar, 2016). It simulates for extended periods of time the hydrologic and associated water quality, various processes on land surfaces and in streams. HSPF uses continuous meteorological records to compute stream flow and pollutants concentrations. HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand (BOD), temperature, pesticides, conservatives, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. Frequency-duration analysis can be done for any time series. Any time step from 1 minute to 1 day that divides equally into 1 day can be used. Any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives or flow diversions (Fonseca et al., 2014; Jia and Culver, 2008; Jung and Deng, 2010; Koutsoyiannis et al., 2007; Langousis and Veneziano, 2007; Langousis et al., 2007; Wu et al., 2006).

The Storm Water Management Model (SWMM), developed by United States Environment Protection Agency - USEPA (United States Environment Protection Agency, 2016) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of subcatchment areas on which rain falls and runoff is generated. The routing portion of SWMM transports this runoff through a conveyance system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each subcatchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps (Liao et al., 2013).

The BASINS system (United States Environment Protection Agency, 2017) combines environmental data bases, models, assessment tools, pre- and postprocessing utilities, and report-generating software to provide the range of tools needed for performing watershed and water quality analyses. HSPF was incorporated into BASINS as the core watershed model. The BASINS physiographic data, monitoring data, and associated assessment tools are integrated in a customized geographic information system (GIS) environment. The simulation models are integrated into GIS environment through a dynamic link in which the data required to build the input files are generated in GIS environment and then passed directly to the models. The results of the simulation models can be displayed visually and can be used to perform further analysis and interpretation.

The USDA (United States Department of Agriculture) - Water Erosion Prediction Project (WEPP) model (United States Department of Agriculture, 2016) represents a new erosion prediction technology based on fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. The hillslope or landscape profile application of the model provides major advantages over existing erosion prediction technology. The most notable advantages include capabilities for estimating spatial and temporal distributions of soil loss (net soil loss for an entire hillslope or for each point on a slope profile can be estimated on a daily, monthly, or average annual basis), and since the model is process-based it can be extrapolated to a broad range of conditions that may not be practical or economical to field test. In watershed applications, sediment yield from entire fields can be estimated (Singh et al., 2011).

European Hydrological System (SHE) is a physically-based, distributed, catchment modeling system produced jointly by the Danish Hydraulic Institute, the British Institute of Hydrology and SOGREAH, France (ARTELIA, 2017) with the financial support of the Commission of the European Communities (Abbott et al., 1986). The SHE developed from the perception that conventional rainfall/runoff models are inappropriate to many pressing hydrological problems, especially those related to the impact of man's activities on land-use change and water quality. Only through the use of models which have a physical basis and allow for spatial variations within a catchment can these problems be tackled. The physical basis and flexible operating structure of the SHE allows the model to use as many or as few data as are available and also to incorporate data on topography, vegetation and soil properties not normally included in catchment models. It does not require a lengthy hydrometeorological record for its calibration and its distributed nature enables the spatial variability in catchment inputs and outputs to be simulated. However, the large amount of data required by the model means that new operation methodologies must be evolved (Bathurst, 1986). Thus spatial scale effects or simply a lack of data may create significant uncertainties in the values of the catchment parameters used in a simulation. These uncertainties will give rise to corresponding uncertainties in the predictions. However, the SHE is able to quantify these uncertainties by carrying out sensitivity analyses for realistic ranges of the parameter values. Even when there is lack of data, therefore, the SHE acts as a valuable “decision-support system”.

MIKE SHE is an European fully distributed physically-based hydrological model (Wang et al., 2012; Wijesekara et al., 2012; Anquetin et al., 2010; Dai et al. 2010; Li et al., 2010; Ma et al., 2010; Smerdon et al., 2009; Zhang et al., 2009; Khu et al., 2008; V´azquez et al., 2008; Zhang et al., 2008). It covers the major processes of the hydrologic cycle and includes process models for evapotranspiration, over-land flow, unsaturated flow, groundwater flow, and channel flow and their interactions.

SHETRAN (SHETRAN, 2016) is a physically-based semi-distributed modeling system for water flow and sediment and contaminant transports in river catchments developed in Europe (Birkinshaw et al., 2010). The physical processes are modeled by finite difference representations of the partial differential equations of mass and energy conservation or by empirical equations. The basin is discretized by an orthogonal grid network in the horizontal view and by a column of layers at each grid square in the vertical view; and the river network is simplified as the links run along the edges of the grid squares (Shi et al., 2013; Zhang et al., 2013; Silva et.al., 2012; Bathurst et al., 2011; Birkinshaw et al., 2011; Santos et al., 2011; Bekele and Knapp., 2010; Birkinshaw et al., 2010; Bovolo et al., 2009; Ramos and Santos, 2009).

TOPMODEL (Community Surface Dynamics Modeling System, 2015) is a physically based, distributed watershed model that simulates hydrologic fluxes of water (infiltration-excess overland flow, saturation overland flow, infiltration, exfiltration, subsurface flow, evapotranspiration, and channel routing) through a watershed. The model simulates explicit groundwater/surface water interactions by predicting the movement of the water table, which determines where saturated land-surface areas develop and have the potential to produce saturation overland flow. Since the early 1990s, TOPMODEL has been widely applied to watersheds everywhere the world because it can provide spatially distributed hydrologic information with available input data (Digital Elevation Model (DEM) data) (Chen and Wu, 2012; Furusho, 2011; Jacobson, 2011; Bouilloud, et al., 2010; Breil et al., 2010; Furusho et al., 2010; Vincendon et al., 2010; Haase, 2009; Quintana-Segui et al., 2009; Rodriguez, 2008)

SWM, SHE and TOPMODEL have the most comprehensive stream chemistry treatment and have evolved to accommodate the latest data sources including remote sensing and geographic information data.
The need to have a reliable chemistry module is due to the fact that human activities have created high nutrient surpluses in agricultural lands. This is actually expected, because of the increasing rate of chemical fertilizer application and the increase in livestock production. Also, the bushfires critically impacted a range of catchments, increasing the community concern about fire and catchment management. To analyze the water quality, some indicators like total nitrogen (TN), total phosphorus (TP) and total organic carbon (TOC), as well as dissolved total nitrogen, dissolved inorganic nitrogen, dissolved organic nitrogen, particle organic nitrogen, dissolved total phosphorus, dissolved organic carbon and particle organic carbon must be estimated. The impacts of bushfire on run-off are highly variable in space and time and will depend on: the type and age of the pre-bushfire vegetation, the extent and intensity of the bushfire, the extent of mortality of the vegetation, and the nature of, and rate of, recovery of vegetation after the fire (Department of Sustainability and Environment, 2011).

The CLUE-S model *(Conversion of Land Use and its Effects-Small scale)* was developed by NIWA (The National Institute of Water and Atmospheric Research, New Zealand). It is a model that is able to dynamically forecast agricultural land use change at the local level, and integrate the various spatial levels and their driving factors related to land use change. Based on empirically quantifiable relationships between land use and driving factors, CLUE-S can be applied to the watershed to simulate several scenarios of the spatial distribution of land use in the watershed. The CLUE-S model is able to simulate the spatial distribution of land use patterns in the near future based on present and historical land use, and on competition between land use in space and time (Mehdi et al., 2012).

RORB (Monash University, 2015) is an Australian general runoff and stream flow model, used to calculate flood hydrographs from rainfall and other channel inputs (See Figure 3.9). It subtracts losses from rainfall to produce rainfall-excess and routes this through catchment storage to produce the hydrograph. It can also be used to design retarding basins and to route floods through channel network. The model can be used both for the calculation of design hydrographs and for model calibration by fitting to rainfall and runoff data of recorded events. The model is distributed, nonlinear, and applicable to both urban and rural catchments. It makes provision for temporal and areal variations of rainfall and losses, and can model flows at any number of gauging stations. In addition to normal channel storage, specific modeling can be provided for retarding basins, storage reservoirs, lakes or large flood plain storage. Can be also modeled base flow and other channel inflow and outflow processes, concentrated and distributed.

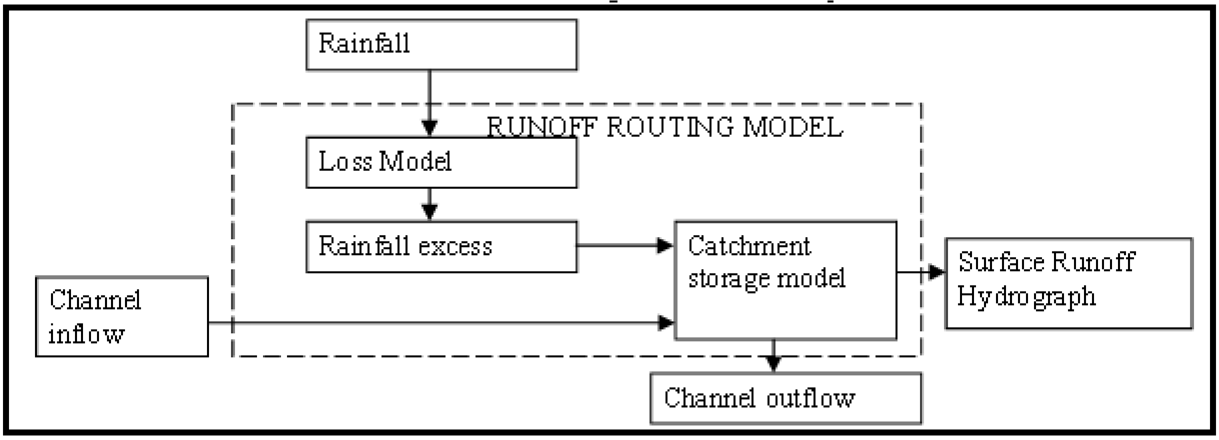


Figure 3.9. Overall RORB Runoff Routing Model (Monash University, 2015)

The model consists of two parts, a loss model and a catchment storage model. Inputs to the model can consist of rainfall on a catchment area or direct inflow to the channel system. In the former case, rainfall is operated on by a loss model to convert rainfall into rainfall-excess, which is then routed through the catchment storage model to produce the surface runoff hydrograph. In the latter case, channel inflow enters the catchment storage model directly (Patel and Rahman, 2010).

The ecohydrological SWIM (Soil and Water Integrated Model) model (Krysanova et al., 2000) was developed based on two models: SWAT (Arnold et al., 1993) and MATSALU (Krysanova et al., 1989). SWIM is a process-based semi-distributed model for river basin and regional scales (Koch et.al., 2013; Krysanova et al., 2005; Krysanova and Becker, 1999; Nash and Sutcliffe, 1970). The model simulates all processes with a daily time step and uses a spatial disaggregation scheme for catchments into sub-basins and hydrotopes. The latter, defined by overlaying sub-basin, land-use and soil maps, are used to simulate all water flows and nutrient cycling in soil as well as vegetation growth, as it is assumed that units that have the same land-use and soil types within one sub-basin behave similarly. Climate as well as land-use, water management and nutrient input to surface waters from point sources are important external drivers for processes simulated in the model. Climate parameters are assumed to be homogeneous at the sub-basin level. Measured or projected climate data are interpolated to the sub-basin centroids by using an inverse weighted distance method (World Meteorological Organization, 2009).

Hydrological processes in SWIM are based on the water balance equation and take into account surface, subsurface and groundwater flows, as well as percolation and recharge of the aquifers (Krysanova et al., 2015). Main external drivers are precipitation and snow amounts, together with temperature and solar radiation influencing snowmelt processes and evapotranspiration potential.

The crop and vegetation module represents an important interface between hydrological processes and nutrients. Vegetation growth, and its decline and harvesting, influence evapotranspiration processes as well as nutrient availability in the soils. Plant growth in the model can be influenced by four potential stress factors: temperature, soil moisture, nitrogen and phosphorus content in soil. The nitrogen module for the soil layers includes four pools: nitrate nitrogen, active and stable organic nitrogen, and organic nitrogen in plant residues, as well as flows: fertilization, input with precipitation, plant uptake, mineralization, denitrification, washoff, leaching and erosion. An ammonium nitrogen pool was added to the nitrogen cycle (Hesse et al., 2012) taking into account decomposition, mineralization, nitrification, volatilization, leaching, erosion and plant uptake processes.

The following pools represent soil phosphorus in SWIM: unstable phosphorus, active and stable mineral phosphorus, organic phosphorus and phosphorus in the plant residue, and the flows: fertilization, sorption and desorption, mineralization, plant uptake, erosion and wash-off (Krysanova et al., 2015). In the applied SWIM version, soluble phosphorus is also allowed to leach vertically through the soil profile (Hesse, 2008). Hesse et al. (2015) made an analysis using SWIM, in Vistula Lagoon located in the south Baltic, with poor and inconsistent input data, missing information on small rivers, and the heterogeneity of spatial data. Despite all the difficulties, the results of model calibration/validation were quite satisfactory, creating a sound basis for the climate impact assessment. The applied method of calibration/validation can be used for other coastal areas and partly-gauged drainage basins.

3.2.5. Models suitable to model the behaviour of chemicals in Victoria

The Soil and Water Assessment Tool (SWAT) was developed by US Department of Agriculture and Texas A&M University Laboratories at Temple, Texas.
The SWAT model belongs to the class of process based eco-hydrological river basin models (Arnold, 2012), which could be defined as continuous-time dynamic models based on mathematical descriptions of physical, biogeochemical and hydro-chemical processes, combining elements of both physical and semi-empirical nature. The process-based models are not fully distributed in three dimensions, but usually include a reasonable spatial disaggregation scheme into sub-basins and hydrological response units (HRUs).
The SWAT model has been applied in various situations, in different climatic areas, across a range of watershed scales, and in varies environmental systems worldwide. There are many SWAT applications found in the literature (Baker and Miller, 2013; Douglas-Mankin et al., 2010; Gassman, 2014; Gassman et al., 2014; Goldstein and Tarhule, 2015; Jha et al., 2013; Krysanova and Srinivasan, 2015; Krysanova and Arnold, 2008; Liersch, 2013; Malagò et al., 2015; Pfannerstill et.al., 2014; Piman et al., 2013; Singha et al., 2015; Sood et al., 2013; Tuppad, 2011; Velasco and Bauwens, 2013; Xu et al., 2013). The research based on SWAT evaluate the hydrological regime and water resources (water discharge, irrigation, and water management); water quality; climate change impact on water quantity and quality; sediment losses; land use and land management change.
In some research papers (Bieger et al., 2015; Xu and Peng, 2013) the calibration and validation methods applied were deficient, and the quality of results was poor. Such an approach does not guarantee that the processes in the catchment were simulated correctly. Especially for large sites, there is a need of a multi-site and multi-variable calibration that involves other components, so, more data.
SWAT development continues, and the model is widely recognized as an integrated tool for multidisciplinary studies at the regional scale in different physiographic and climatic conditions. It is now one of the most widely applied river basin-scale models worldwide (Krysanova and White, 2015).

eWater Source **– Australia's National Hydrological Modeling Platform** (NHMP) – is developed by eWater CRC, Australia (eWater, 2015a). It is designed to simulate all aspects of water resource systems to support integrated planning, operations and governance from urban, catchment to river basin scales including human and ecological influences. Source accommodates diverse climatic, geographic, water policy and governance settings for both Australian and international climatic conditions (eWater, 2015a). Source provides a consistent hydrological and water quality modeling and reporting framework to support transparent urban, catchment and river management decisions. Fundamental to this design is the flexibility which makes it readily customizable and easy to update as new science becomes available. New capabilities can be incorporated via pluggins developed to suit particular needs while maintaining the overarching consistent decision and policy framework.

eWater is a conceptual, semi-distributed model and it applies the flow accumulation principles. The catchment is divided into sub-catchments, and every sub-catchment can have many functional units (FU). A FU is an area that has a certain hydrological behaviour. In the same FU, one or many landuse can exist. Also, two areas with the same landuse can be in different FU.

The model integrates rainfall runoff models and constituent generation models. Various scenarios can be created.

The model requires the minimum of input parameters: the physical data (DEM, landuse, soil properties), the river flow and nodes (as a shapefile) – points where the pollutants are considered to be released in the water) and the meteorological data (rainfall, evapotranspiration). Also, the model needs water quality parameters, in order to calibrate and to validate it.

The outputs of the model are the water quality parameters' concentrations, at the same time-step such as the inputs, generated in the nodes.

eWater is the Australia's National Hydrological Modeling Platform because it is an Integrated Water Resources Management (IWRM) tool combined with water policy and governance capability. eWater CRC and its Australian Government and industry partners have completed more than 100 Source applications, and inform on water policy, water sharing plans and catchment management (eWater, 2017a).

eWater model and its tools, were used in many catchments in Victoria: **Melbourne's inner north-** water management; **Yarra River -** Catchment activities influencing water quality; water quality and flow management influencing river ecology; Murray River - Integration of hydrologic, hydraulic and ecological response models to support adaptive management; **the Goulburn River** - the floodplains of the highly regulated Goulburn

River have experienced a significant reduction in overbank flow events; **City of Melbourne -** to calculate how much stormwater is available from its urban catchments to see if there's enough to irrigate parks, gardens and sports fields (eWater, 2017).

3.2.6. Conclusions

The aim of hydrological modeling is to understand and interpret the catchment hydrological behaviour. The models are use to predict the water resources or water quality. There are many types of hydrological models. A model is chosen taking into account various factors such as the purpose for which this model has been used or the availability of data. Whatever model is applied, the model user needs appropriate input data depending on the capacity of the model.

The model must be validated and evaluated by comparing the outputs of the model with the measured data. However, the performance of the model is very dependent of the user's experience.

To predict the water quality in a catchment, the best option for the user is to run a site-specific hydrological model, conceptual, semi-distributed. This type of model is based on mathematical equations and empirical parameters which can take different values depending on the catchment characteristics. Being a semi-distributed model, the parameters are assigned to each grid cell, but cells with same values of parameters are grouped. This feature increases the accuracy of the model's outputs, but at the same time keeping the running time in reasonable limits.

The models which were used very often for water quality forecast in catchments are SWAT (The Soil and Water Assessment Tool) and eWater.

The SWAT model was applied in a broad range of catchment scales, in various environmental conditions and climatic areas and in many studies the results were satisfactory or good model in terms of river water quality.

eWater provided very good results when it was used in Australia, in the projects that aimed to understand the catchment behaviour. The outputs of the model were used for water resources management and decision making.

Having an integrated water resources management tool combined with water policy and governance capability for Australia, eWater can be considered the most suitable hydrological model for Victoria.

4. PILOT STUDY: HYDROLOGICAL AND RELATED CHARACTERISTICS

4.1. Introduction

In this thesis, a spatially based approach for local government management was proposed, in order to predict water quality parameters after bushfires. La Trobe catchment was selected as the pilot study area for application of hydrological models with water quality component. This region is a bushfire prone area and the Department of Environment, Land Water and Planning manages a water quality database for this catchment. In this chapter, the geography of the region is discussed, the criteria for the selection of the study area, and the overall challenges to the implementation of spatial technology.

4.2. Selecting a study area

The selection for a study area is governed by a number of criteria.

4.2.1. Bushfire prone area and has had bushfires

Bushfire is a natural phenomenon in Australia. Moreover, Victoria is one of the most bushfire prone areas in the world with a long and tragic history related to bushfires. This criterion was very easy to meet. Many areas in Victoria were burnt in the last years. Some examples will be discussed (Country Fire Authority, 2017). In December 2002, fires in Big Desert Wilderness Park and in the adjoining Wyperfield National Park burnt 181,400 hectares. In January 2003 eighty-seven fires were started in the north-east of Victoria, burnt 1.3 million hectares, and affected Mt Buffalo, Bright, Dinner Plain, Benambra and Omeo.

At the end of 2005, more than 500 fires started across the state and finished at the end of January 2006. They occurred in the Stawell (Deep Lead), Yea, Moondarra, Grampians, Kinglake and Anakie areas.

The fires burned about 160,000 hectares.

From mid-December 2006 to mid-March 2007, more than 1,000 fires burnt across Victoria. The total area burned exceeded 1,200,000 hectares.
The 2009 Black Saturday bushfires were the worst in the Australia's history. The fires burned almost 430,000 hectares of land, including 70 national parks and reserves and more than 3,550 agricultural facilities.
Also, Victoria had a significant fire season during December and mid-March 2012–2015. The fire burnt more than 190,000 hectares. Major fires included the Aberfeldy-Donnellys Creek, Harrietville, Chepstowe, and the Grampians fires.
The Australian nature is resilient; houses are rebuilt, the destroyed infrastructure can be repaired; but the worst thing was the loss of human lives.

4.2.2. The need for data

To be able to apply a hydrological model in a catchment requires certain input data. Also, there is the necessity to calibrate and validate the model with water quality parameters. So, one of the important criteria for choosing the studied catchment is the availability of data. If the digital elevation model (DEM), landuse, river flow and meteorological data can be found for the whole of Victoria, the water quality data is limited. Even if there are many monitoring sites across the state, some of them were closed twenty years ago, others measure only rain and flow, and most of the monitoring stations have sparse, missing or inaccurate water quality data (Department of Environment, Land, Water and Planning, 2017). In fact, this criterion is a challenge for a user who wants to apply a hydrological model in a catchment from Victoria.

4.2.3. The site area needs to be big enough for reasonable modeling

The hydrological model applied in this research (*eWater* public version) is able to model water quality parameters in a catchment which is less than 5000 squared kilometres and with less than 20 nodes (eWater, 2016d). The model does not have a minimum area that can be analysed. At the same time, the user must consider how representative can a small catchment of about 500 squared kilometres (for example) be for the State of Victoria. When there are bushfires in the catchment, the pollution sources considered in the model are obtained by the combination between landuse, fire and rain intensities. So, especially for these periods, in a small area the number of combinations is too small, so the results cannot be generalized for bigger area.

4.2.4. The site would preferably be mainly pristine to simplify the modeling

The focus of this research is to analyse the impact of bushfires on water quality using modeling tools. To simplify the method and to obtain more accurate results, a mainly pristine area must be considered. It is important that there are no other sources of pollution in the area, so that the main source of pollution is from bushfires. Therefore the water quality data after bushfires can be very well evaluated. On the other hand, because the bushfires in Victoria also burnt some landuse areas (agriculture or urban), there is a necessity to find a catchment which has some various type of landuse, as well. In these areas, the pollution from bushfires can be highlighted, by comparing with the periods without fires.

4.3. Latrobe catchment

Latrobe was selected to be the catchment area for this research. This is a bushfire prone area and the 2009 Black Saturday bushfires affected large areas in this catchment. The area of the catchment is 2899.53 square kilometres. It is less the 5000 square kilometres, so it is very suitable for *eWater Source* modeling. On the other hand, the area is large enough to include all the necessary combinations between landuse, fire and rain intensities, representative of similar catchments throughout Victoria. The most part of the catchment is covered by forest, in the upper sector of the river, which is a pristine area; but there are also crops, horticulture, grazing and urban landuse types, in the lower Latrobe (Victorian Environmental Water Holder, 2017). Finally, the research in this area can be undertaken based on the data availability. There are 32 monitoring points in the Latrobe catchments, but only the water quality data from 7 points can be used, being continuous and reliable data.
Figure 4.1 shows an image of Latrobe River.

Figure 4.1. La Trobe River – January 2017

Latrobe Catchment is part of West Gippsland which is situated in Victoria, Australia, as shown in Figure 4.2.

Figure 4.2. The map of Latrobe Catchment, in Victoria created with data (layers) from Land Victoria, 2016

The catchment has a maritime temperate climate with the mean temperature between 12.9 and 26.6 in February and between 3.7 and 13.6 in July, computed for period 1984 – 2017 (Bureau of Meteorology, 2017d).

The average annual rainfall across the municipality is around 800-1000 mm per year with a strong seasonal cycle (Southern Rural Water, 2014**)**.

The Latrobe Basin water yield, which is defined as the mean annual run-off for the Latrobe Basin, is 887,000 megalitres per annum. The Latrobe floodplain basin and wetlands has as its major tributaries Tanjil, Tyers, Moe and Morwell Rivers and Traralgon Creek which drain into the Gippsland Lakes and contribute to water quality and quantity (see Figure 4.3). Water quality within the Latrobe River varies greatly but the condition of the overall Latrobe River has been rated as ‘poor’ in the West Gippsland Regional River Health Strategy (Department of Environment, Land, Water and Planning, 2006).

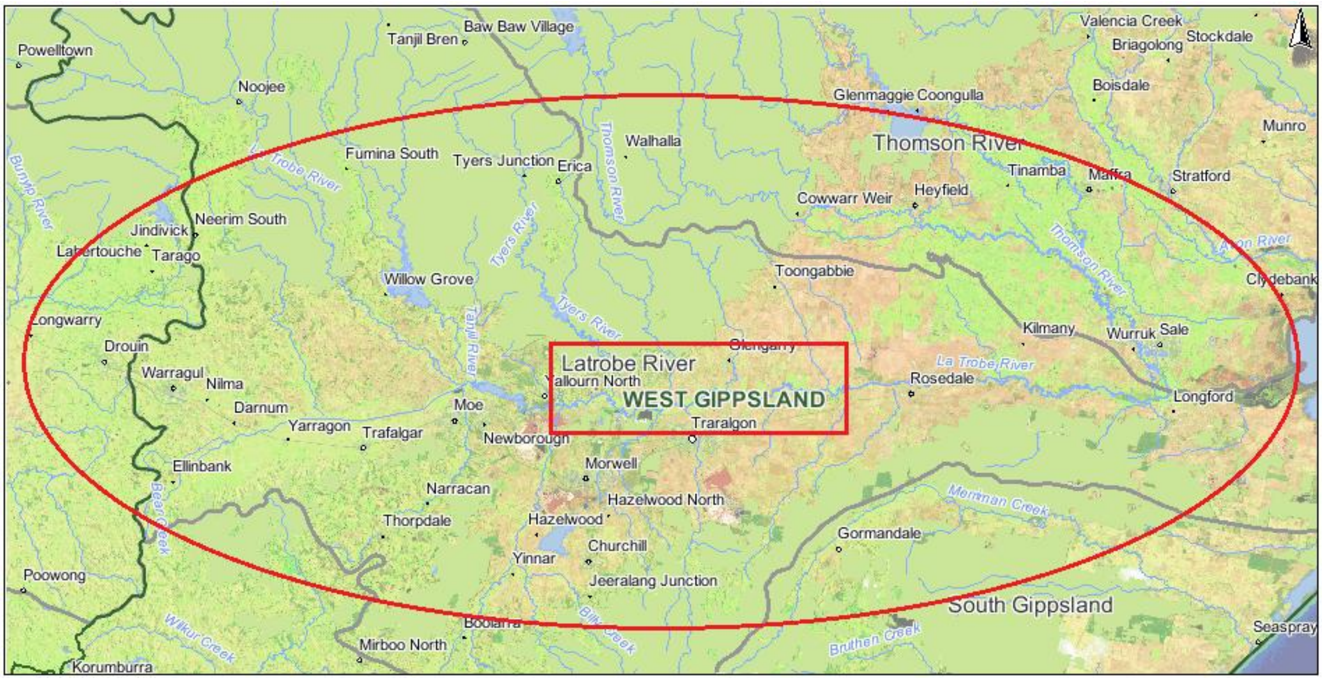


Figure 4.3. La Trobe River and its main tributaries (Victorian Government, 2014b)

The Latrobe River Basin contains some of Victoria’s most significant river systems and the demand on these resources is considerable (see Figure 4.4). The nation’s largest pulp and paper mill and most of the State’s power industry fall within its boundaries. Major population centres include Moe, Morwell, and Traralgon.

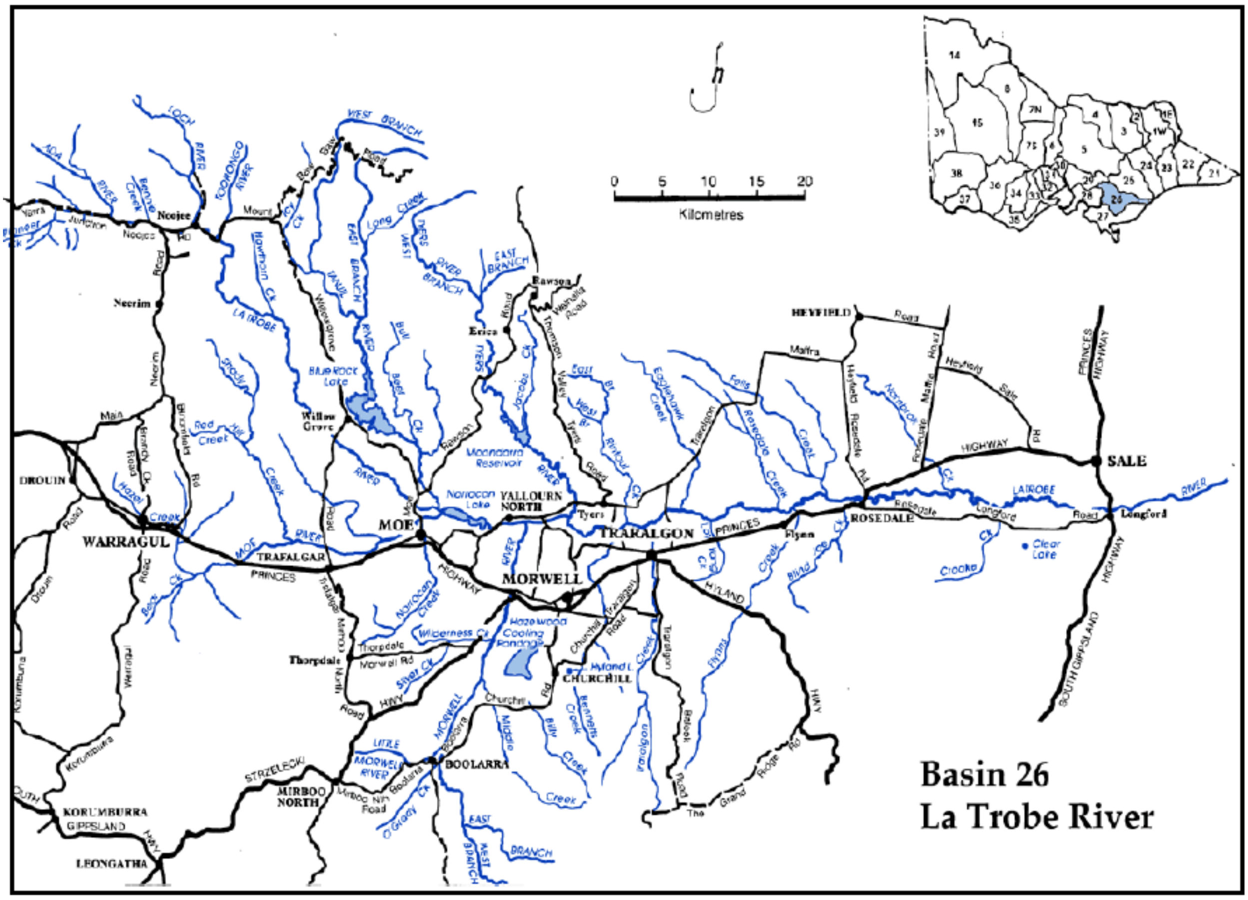


Figure 4.4. Basin 26 – La Trobe River, Local Management Plan (Southern Rural Water, 2014)

The rivers of the Latrobe Basin have historically had plenty of water (Environment Protection Authority, 2002). The Latrobe and its tributaries, the Tanjil and the Tyers, flow from forested upper reaches through extensive floodplain areas to the fresh water marshes of the Gippsland Lakes Ramsar listed wetland environment (The Ramsar Convention Manual, 2013). Unfortunately, those floodplain areas are also home to Victoria's brown coal industry which has had a very significant impact on the river system (Environment Victoria, 2015).

Latrobe Valley contains a great diversity of native plants and fauna, such as the Powerful Owl and Barking Owl, Strzelecki Koala and Tree Goanna, Grey Kangaroo, Swamp Wallaby, Wombat, Echidna are and Platypus (Latrobe City Council, 2014). Many more animals, especially invertebrates, probably remain to be identified. Four plant species, one plant community and three of the animal species are listed under the Federal Environment Protection and Biodiversity Conservation Act 1999, two plants and ten animals are listed under the state Flora and Fauna Guarantee Act 1998, and seven species of animals are listed under international treaties. All these 30 plant species and 24 animal species are rare or threatened in Victoria. Over 23 different classes of native vegetation can be found and there is a great deal of variation within those classes (Department of Environment and Water Resources, 2007).

Substantial change has occurred in the La Trobe catchment and its tributaries catchments since early settlement. Forests have been cleared, extensive gold mining operations were common, large-scale coal mining and power generation, industrialization, development of intensive agriculture, and impoundment and diversion of water from the major tributaries has occurred.

As a consequence of land use changes within these catchments, the Latrobe, Thomson and Avon systems contribute more than twice the nutrient inputs to the Gippsland Lakes than all other riverine inputs (Figure 4.5). The Latrobe River provides approximately half the flows and two thirds of the nutrient load to Lake Wellington (Robinson, 1995).

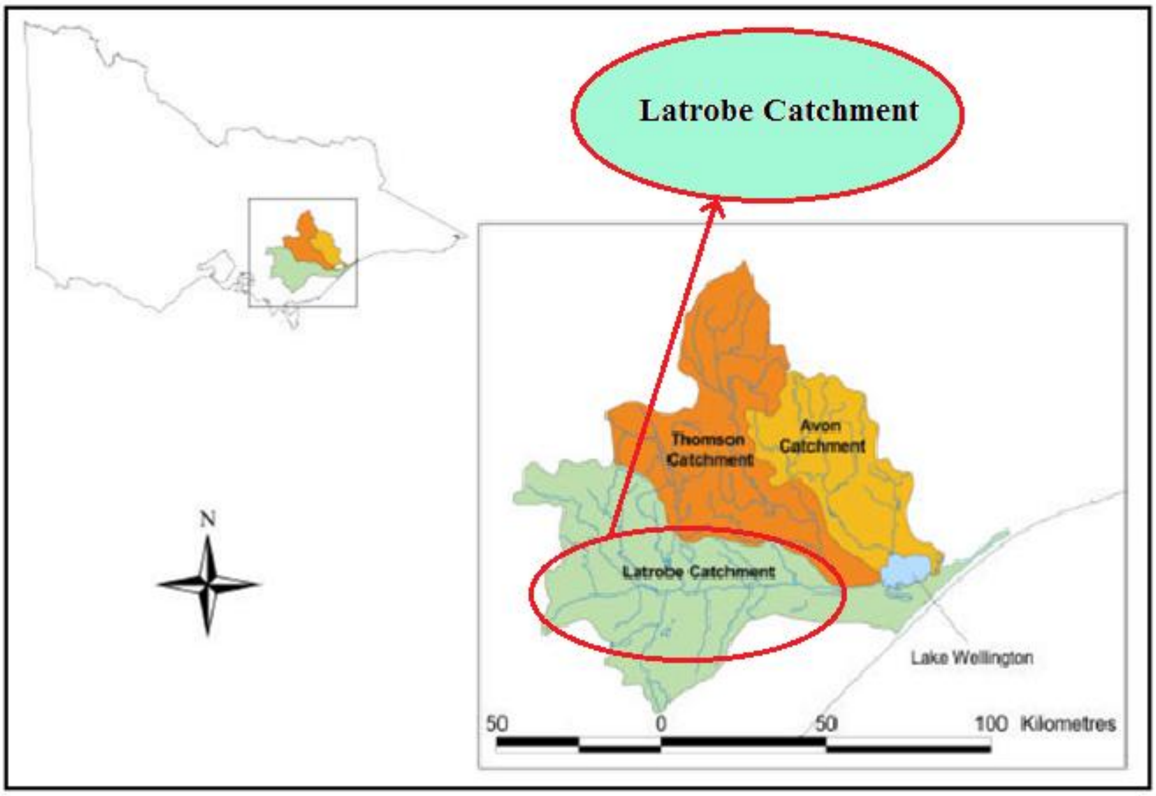


Figure 4.5. Location of the study area: Latrobe catchment near Thomson and Avon catchments in West Gippsland, Victoria (Environment Protection Authority, 2002)

Water quality in the Latrobe River is impacted to some extent by agricultural and urban and runoff (Environment Protection Authority, 2002). These inputs are addressed through EPA licensed discharges and best management practice. Ongoing programs will be required to address water quality issues in the Latrobe River system and the Gippsland Lakes catchment (Environment Protection Authority, 2002).

The Department of Sustainability and the Environment (DSE) initiated the Victorian Environmental Flow Monitoring and Assessment Program – VEFMAP (Chee et al. 2009) to evaluate ecosystem response to environmental flows in eight regulated rivers, which include the Thomson and Macalister rivers (Figure 4.6), the most important tributaries of the lower Latrobe. The program monitors for fish, vegetation, physical habitat, and water quality responses to environmental flow releases.

Figure 4.6. Thomson River and Macalister River, the tributaries of La Trobe River, (Victorian Environmental Water Holder, 2014)

West Gippsland Catchment Management Authority and Parks Victoria have collaborated to undertake physical and biological monitoring in the lower Latrobe wetlands in 2010/11, in order to support the preparation of the seasonal watering proposal and its implementation. The program included monitoring of water levels, water quality, vegetation, macroinvertebrates and waterbirds, and will continue in 2011/12 (Seasoning Watering Plan 2011-2012, June 2011, West Gippsland Catchment Management Authority).

Environment Protection Authority Victoria has considered water as ‘the fundamental resource’ that sustains all activities within the region, and considers water quality to be the single most important regional issue (Environment Protection Authority Victoria, 2015b). Much of the tourism of Gippsland is centreed on water resources and the natural beauty of waterways and wetland ecosystems. In 2013-2014, the tourism industry contributed an estimated $1.2 billion to the Gippsland economy and employed approximately 12,400 people (Tourism Victoria, 2015).

Tourism leads to additional pressures on water resources in the region, and relies on the maintenance of high water quality and natural values to support the industry.

4.4. Overall challenges to the implementation of spatial technology

The spatial technologies that can be used in water resources and water quality management and planning are based on computer software developed for these purposes as well as satellite imagery and satellite positioning systems (Baynes, 2007). The main computer software used in spatial technology field is the Geographic Information Systems, such as ArcGIS developed by ESRI (Environment Systems Research Institute, 2016) or QGIS (Quantum GIS, 2016) which is an open-source application, both made for vector and raster representation and for modeling. The computing power has increased in the last years and the commercial competition made the geographic information systems' developers to improve the software and to make it easier, with a friendlier interface. The tasks that can be done using GIS software are very broad and complex, from simple mapping to complex analyses and modeling of various aspects related to environment, social and economic issues. The GIS software is able to be used to analyse the satellite imagery and satellite positioning systems data (Environment Systems Research Institute, 2010). The satellite data availability started after USA launched Landsat 1, in 1972 (National Aeronautics and Space Administration, 2005). Land management became more effective with the satellite data which was able to detect changes on the Earth's surface such as landuse and landcover (biomass and canopy cover). Later, commercial satellite imagery was launched, IKONOS sensor being able to record high resolution data. However, this data is very expensive (Satellite Imaging Corporation, 2016).

On the other hand, GPS maintained by the U.S. Department of Defence (United State Government, 2016) enables the user to have the position, time and velocity. Other systems were developed by the European Space Agency (ESA). They developed a satellite radio-navigation program, named Galileo (European Space Agency, 2016), and using the ground stations, the system reached the smallest horizontal positioning error (10 cm).

Taking into account these improvements, nowadays the flexibility and the speed with which the analyses and assessments can be made using spatial technology increased. Both satellite and GPS data are available to be use in GIS software, the challenge being related to the limitations of the technology.
There are many positive results reported in the literature (CRC for Spatial Information & ANZLIC – The Spatial Information Council, 2008; Australian Local Government Association, 2007) about applying the spatial technology at national, state and local level, in Australia, so it can be noticed the evolution from apprentice to experience stage.
The management, planning, and decision making processes are very important in every country, but they must be based on reliable data (Land & Spatial Information Department of Natural Resources and Mines, 2015). The lack of data or the inadequate/inaccurate data lead to wrong decisions. There are some limitations from this point of view because, to be able to make an assessment, an authority needs not only satellite data (which are available), but many other type of data, and the collection of this information can be difficult. Also, the storage and management of this data can be demanding. Last, but not least, the government bodies need specialists to handle this information, to be able to make the analyses and to draw conclusions.
Spatial technologies make easier the flow of information between citizens and government authorities and help them to solve the problems in a rapid and smart way (Rajabifard et al., 2007). However, there are still many things that must be improved at all levels of government. For example, the large sets of data slow the work of the staff to satisfy the public requests. The database must be very organized and adequate funding must be provided to ensure that the quality of data is maintained. Also, the agreements between the government's authorities at all levels must continue to exist and the connection between them must be more evident (Victorian Spatial Council, 2015).

4.5. Conclusions

This chapter presented the characteristics of the study area chosen for this research. The catchment's area is less than 5000 km^2 and contains Latrobe River and its tributaries, being one of the Victoria's most significant river systems.

This area was chosen for this study because it is a bushfire prone area where there were many fires and the authorities faced with the necessity to manage of water quality after fire. Also, the area of the catchment is suitable for the chosen hydrological model, and it is large enough to be representative for the entire Victoria. It consists of pristine area, but also of various types of landuse. Another important reason for choosing this region is the availability of data.

The spatial technologies used to plan and manage the water quantity and quality is based on GIS software, satellite and GPS data. The decision making processes are very important in every country, but they must count on reliable data. The lack of data or the inadequate/inaccurate data lead to wrong decisions. The spatial technology was successfully implemented at all government levels in Australia, but there are still some improvements to be done.

5. DEVELOPMENT OF THE SPATIAL DATABASE

5.1. Introduction

The previous chapter discussed the needs for a pilot study. In this chapter the data needed for this research and their sources are reviewed. It was showed how these data were prepared to create the database for modeling. Also, the workflow and the methodology used for data analysis are explained. It is found that there are some missing data in the database and it was highlighted the importance of a continuous and reliable database.

The data used in this research can be divided into two categories: the input data (such as pollution, meteorology, hydrologic properties of soil, elevation data and hydrology), which are used to run the hydrologic model, and the water quality data, which are used to calibrate and validate the model.

The datasets are available from various authorities' databases. There are available water quality data in various monitoring stations, but they are not continuous and don't exist for all periods of time. Also, many monitoring sites are now closed.

The data are monthly data and they are not computed using the daily data, they are just measured one time every month, which means that they have a high uncertainty.

These are the reasons why a research based on these data has some important limitations.

5.2. Background

In chapter 2, section 2, the water quality management responsibilities of the Australian Government and other agencies were reviewed. It can be noticed that there are many agencies involved in monitoring, assessment and management of water quality, as well as collecting, analysis and disseminating information. It can be seen a high interest in water quality so it is considered very important for the wellbeing of the community.

Water quality assessments in Victoria are based on data from a number of sources. There are reports written by the EPA (Environmental Protection Authority, 2016b), CSIRO (Commonwealth Scientific and Industrial Research Organisation, 2016) or many other agencies providing long-term water quality analyses within Gippsland catchments, based especially on monitoring.

Water quality monitoring campaigns are very expensive. For example, for 5 collaborative water quality projects undertaken in 2009-2015, Department of Environment and Heritage Protection spent about AUD $11 millions (Department of Environment and Heritage Protection, 2008).

In every catchment there are different landuse types, various sources of pollution and a variable response of environment to the stressors. To make a reliable spatial-temporal analysis, the data must be collected from many monitoring points. Especially after a big rainfall event following a fire that burned a large area, the various water pollutants could grow to alarming levels. The rain washes the burnt land, leading to post-fire erosion, carrying ash, heavy metals, nutrients, and other substances into streams. The impact of fires on vegetation and fauna is easy to be observed, but the impact on water is sometimes hard to be estimated.

A more viable way to evaluate or to predict the water quality is through hydrologic modeling. To use a model, a database must be created and used as input.

5.3. Products required to create the database

The necessary data for modeling include elevation data, the location of the monitoring sites, landuse data, meteorological data, hydrological data, which are used as input data, and the water quality data which is used for calibration and evaluation of the model.

5.3.1. The digital elevation data

Initially, to create a project, a digital elevation model (DEM) must be uploaded in *eWater*. The data for this can be downloaded from the DELWP website (Department of Environment, Land, Water and Planning, 2015c), as contour data, for the entire State of Victoria. The spatial resolution of the data is 30 metres. The contours can be transformed into Triangular Irregular Networks (TIN) using 3D Analyst Tools from ArcMap. Then, the TIN can be transformed into a DEM, using Conversion tool form 3D Analyst. The DEM created in this way must be uploaded in eWater, and it is the base of the project which is meant to model the water quality in the catchment. Unfortunately, the DEM had sinks that were not filled, and eWater was not able to establish the flow directions in the catchment.

Sinks and peaks in elevation data are usually errors due to resolution of the data or to the rounding of elevations' values to the nearest integer value. A digital elevation model (DEM) must be processed to remove all sinks. Sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous and may not work properly. The Fill tool, from ArcGIS Spatial Analyst, uses the equivalents of several tools, such as Focal Flow, Flow Direction, Sink, Watershed, and Zonal Fill, to locate and fill sinks. The tool iterates until all sinks within the specified z limit are filled. As sinks are filled, others can be created at the boundaries of the filled areas, which are removed in the next iteration. The tool can also be used to remove peaks, which are false cells with elevation greater than would be expected given the trend of the surrounding surface.

After filling the sinks, in ArcMap, the resolution became too low (45 metres). Still, because the resolution was not appropriate for hydrological modeling, eWater was not able to set the flow directions for the entire catchment (see Figure 5.1).

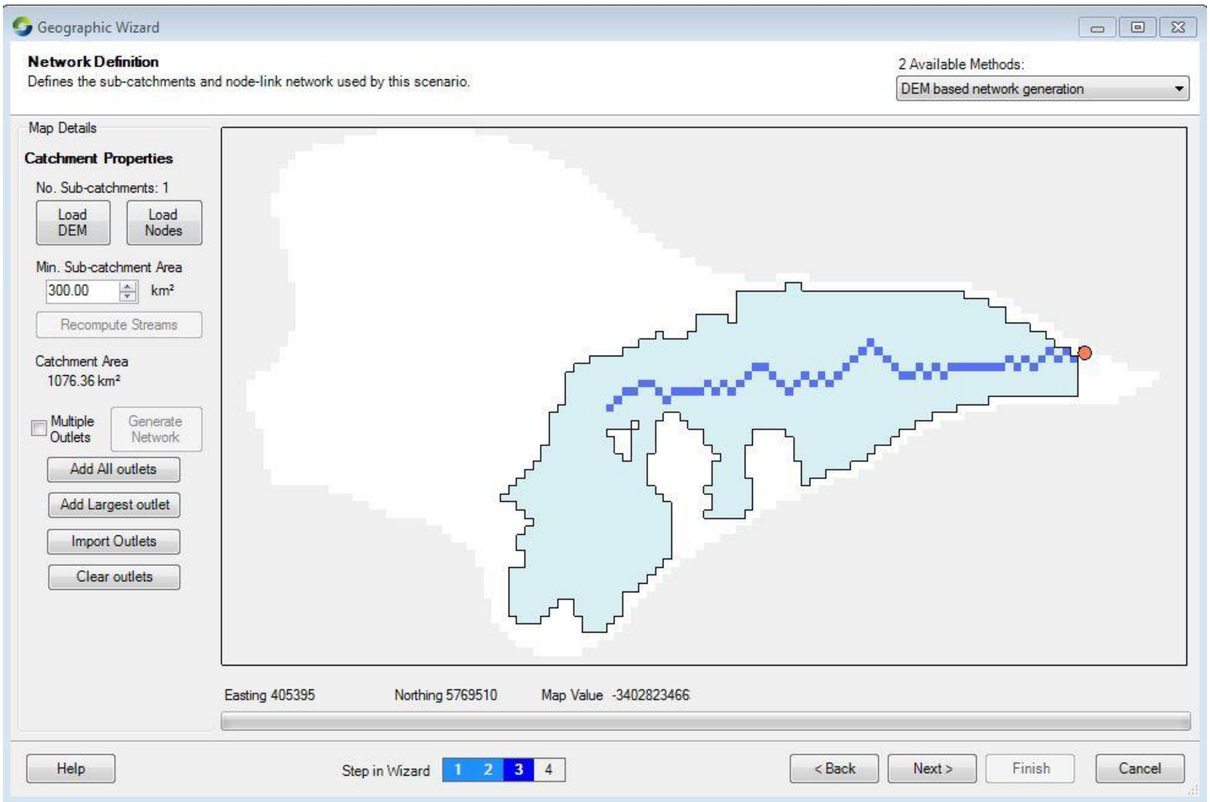


Figure 5.1. Not suitable DEM used for eWater project: eWater was not able to create the flow directions for the entire catchment, only for a small part of it

A better option to build the DEM, was the data provided by Geosciences Australia, from their website. The contour data downloaded from their website gave the possibility to create a DEM with 5 metres resolution. After filling the sinks, the resolution decreased at 25 metres. The value was good enough, so that eWater was able to set the flow direction in the entire catchment (Figure 5.2).

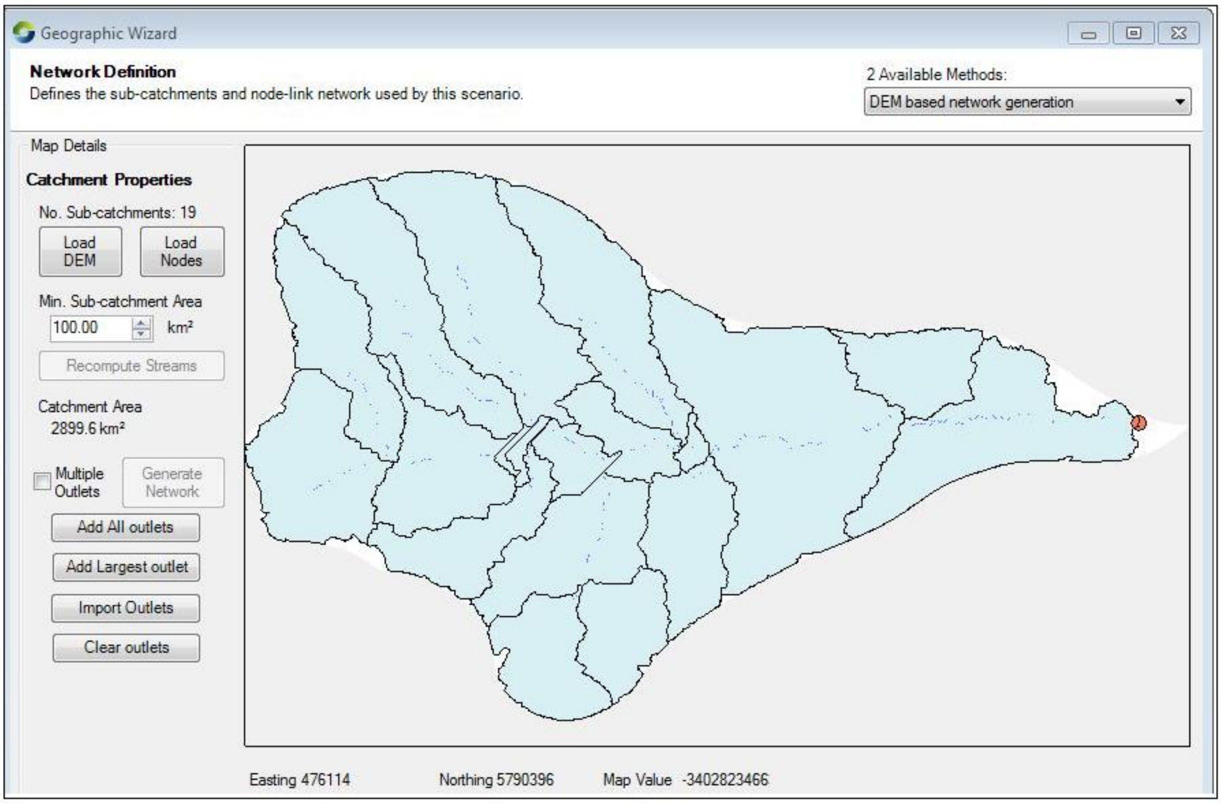


Figure 5.2. Latrobe catchment in eWater - the model set the flow direction for the whole catchment, the red point being the outlet, which is the last point of the catchment

The minimum sub-catchment area can be modified, and by decreasing this minimum sub-catchment area, the number of sub-catchments increases, the accuracy of the output data increases, but also the running time increases considerable. In a project, between the number of sub-catchments and the minimum sub-catchment area must be a balance between a good accuracy and acceptable running time. This balance was achieved by running the model hundreds of times and analyzing the outputs and the running time.

5.3.2. The monitoring points

A shapefile with the monitoring points is also needed in the project (see Figure 5.3). The points and their latitude and longitude were saved as an Excel file. Then the file is imported in ArcMap and the points are mapped. The file is saved as shapefile and it is uploaded in *eWater*, in a certain step. In these points, *eWater* required csv (comma separated values) files with rain, evapotranspiration and river flow. This data must be downloaded from the Bureau of Meteorology website (Bureau of Meteorology 2017a, 2017b, 2017c) and uploaded in the model. In the same points, *eWater* will provide the outputs: the modeled concentrations of the water quality pollutants.

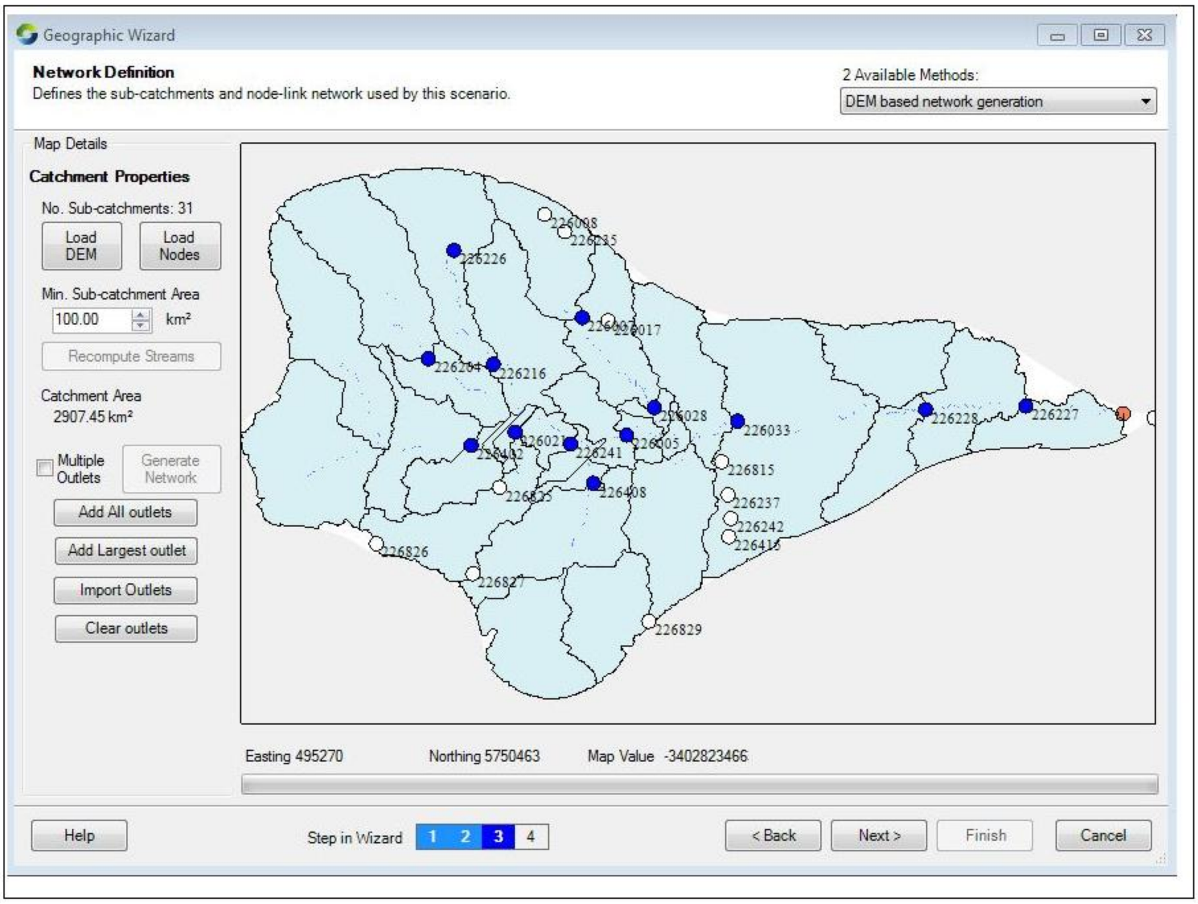


Figure 5.3. The monitoring points: the shapefile uploaded in eWater

5.3.3. Landuse and pollution data

A possible set of landuse data can be found on the *eWater* website. This data set provides maps of land cover type for 1990 and 1995 for the intensive Landuse zone of Australia. Source data for this data set are from the Australian Land Cover Change (ALCC) project and the custodian of the data is the University of Melbourne (eWater Toolkit, 2016). Unfortunately, this dataset has missing data in the Latrobe catchment, as it can be seen in Figure 5.4. So, using it might increase the errors of the modeled data.

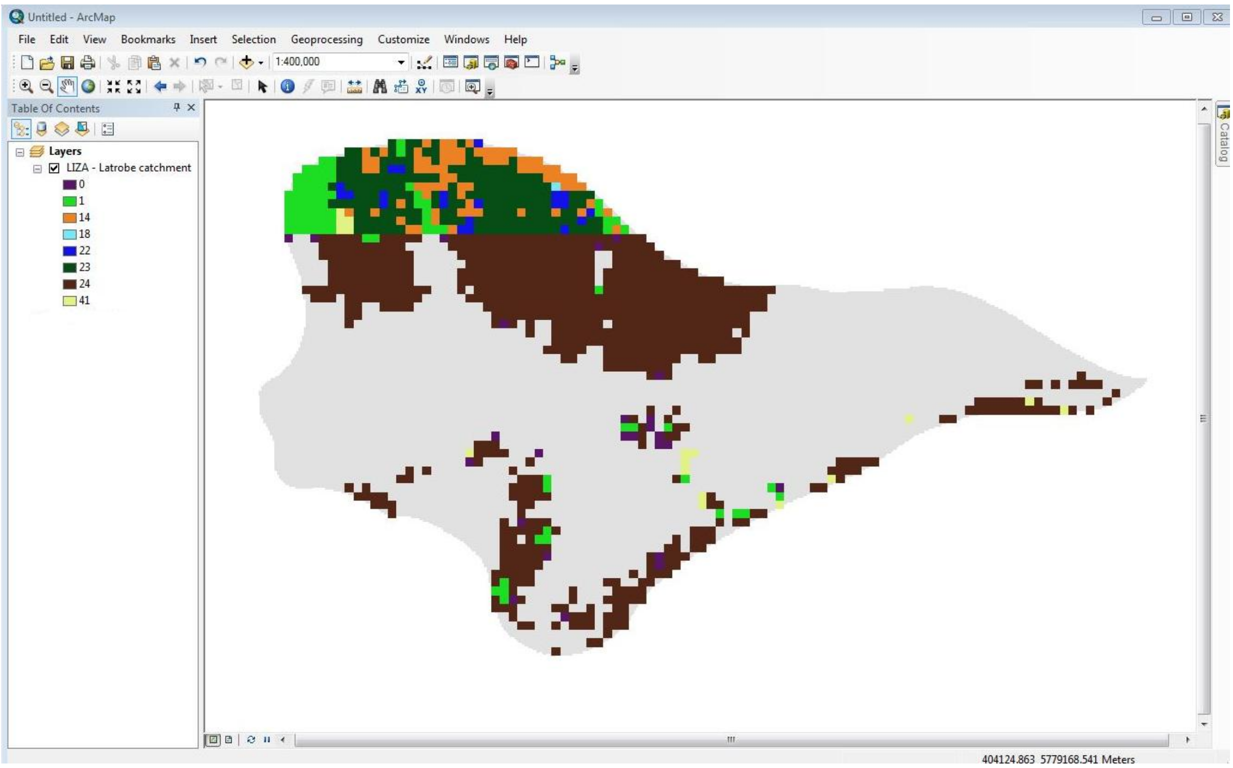


Figure 5.4. LIZA data for Latrobe catchment (eWater, 2017b): the grey colour means lack of data

A reliable dataset for landuse is the Victorian Land Use Information System (VLUIS) dataset (Figure 5.5), which was created by the Spatial Information Sciences Group of the Agriculture Research Division in the Department of Economic Development, Jobs, Transport, and Resources (Victorian Government, 2015). It covers the whole Victoria and describes the land use and land cover for each cadastral parcel across the state, biennially for land tenure and use and annually for land cover; for each year from 2006 to 2015. The data can be provided as a spatial dataset or in tabular format.

Land use means the purpose to which the land cover is committed or the property type. Land cover refers to the physical surface of the earth, including various combinations of vegetation types, soils, exposed rocks and water bodies as well as anthropogenic elements, such as agriculture and built environments.

The Victorian Land Use Information System (VLUIS) is an ongoing project designed to maintain and manage the Victorian land use mapping dataset.

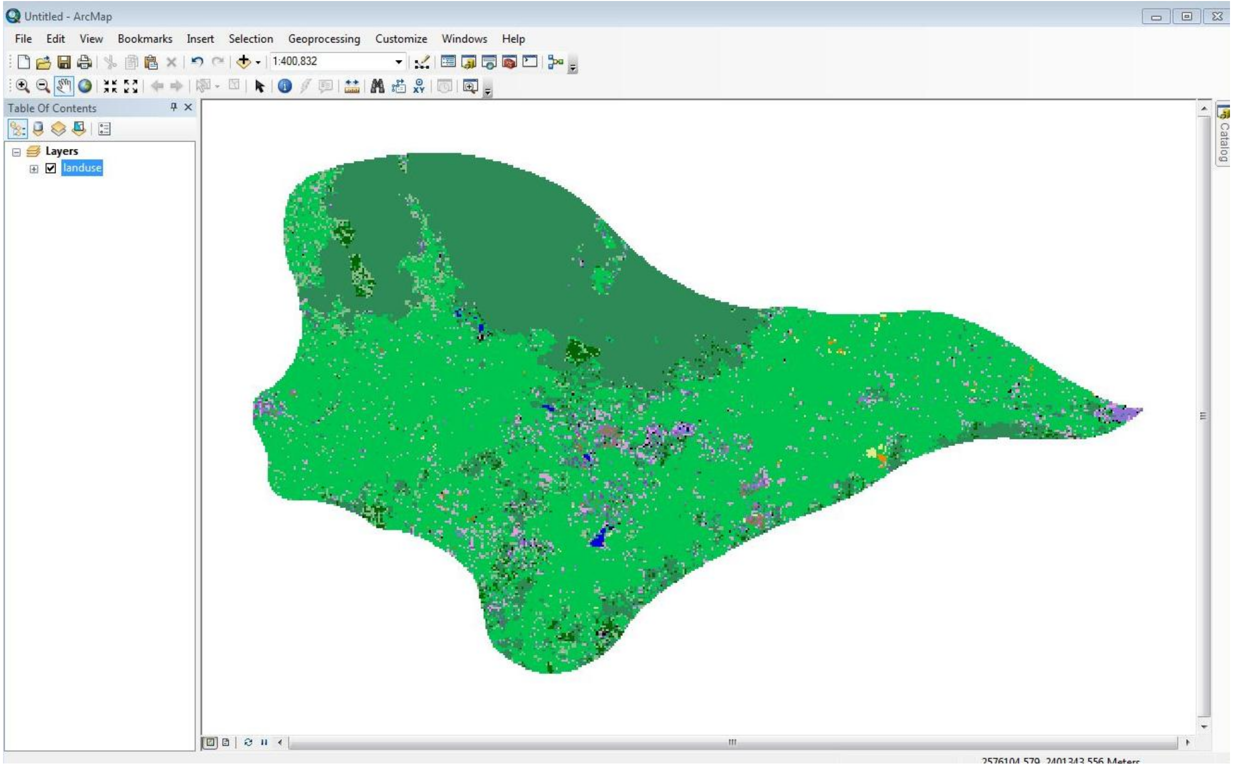


Figure 5.5. Victorian Land Use Information System (VLUIS) in the Latrobe catchment (Spatial Information Sciences Group, 2016)

This dataset will be used as input data in *eWater Source*. The pollution sources are due to the landuse and landcover. When in the catchment there are bushfires, there are additional pollution sources. They can be quantified by combining the bushfire intensity with rain intensity, for a certain type of landuse/landcover. In this way, many classes (combinations between landuse, fire intensities and rain intensities) can be built, the number of classes being related to the computer resources and the desired accuracy of the output data. A high number of classes needs a powerful computer; on the other hand, if the number of classes is too low, the accuracy of modeled data is low. The optimal option is to create a number of combination classes, so the *eWater* to be able to process the input data, but, after modeling, to obtain reliable water quality parameters.

5.3.4. The meteorological data

The meteorological data refer to the precipitation and evapotranspiration, available on the Bureau of Meteorology (BOM) website (Bureau of Meteorology, 2017a).
Rainfall comprises all forms of water that fall from the clouds and reach the earth surface: liquid - rain or drizzle and solid - hail or snow (Ahmad et al., 2017). The rainfall

is recorded using rain gauge, which is the standard instrument built with this purpose. The data are measured in millimetres. Rainfall is generally observed every day at 9 am local time and is a measure of the total rainfall that has been received over the last 24 hours. In some cases, there are available more observations.

Precipitation is most commonly termed rain and includes rain, drizzle, hail and snow. The type of precipitation (when observed) is recorded along with the amount of precipitation.

Climate data must comply with the quality rules, which are applied over a period of time. If there are no errors found in the database, the data are published on the BOM website. Data which have not yet completed the quality control procedure are marked correspondingly.

From various reasons, the stations can be closed, reopened or upgraded, and this can cause breaks in the recorded database. Also, the gaps in the database can be due to a damaged instrument or the failure of an automatic weather station.

The precipitation data can be downloaded in csv (comma separated values) file format, from Bureau of Meteorology website (Bureau of Meteorology, 2017b).

Evapotranspiration (ET) represents the overall transfer of water, as water vapor, to the atmosphere from both vegetated and un-vegetated land surfaces (Ahmad et al., 2017). It is influenced by climate, availability of water and vegetation. Evapotranspiration is calculated by BOM, based on some recorded parameters that characterize the environment, such as temperature, vapor pressure and solar global exposure. Data is available on BOM website (Bureau of Meteorology, 2017c), as daily data, and can be downloaded as text files, then imported in Excel and saved as .csv (comma separated values) or .xls (Excel) files.

5.3.5. The hydrological data

The hydrological data are the flow of river in certain points, and are measured usually in Ml/day (Megalitres per day). These data are available on the Department of Environment, Land, Water and Planning website. The data were recorded daily, for various periods of time in various locations from the entire Victoria (Department of Environment, Land, Water and Planning, 2015d).

5.3.6. The fires data

The fires intensity data recorded from various areas from Victoria are available on the Victorian Government website (Victorian Government, 2017). Unfortunately, in the Latrobe catchment there is a gap in the database.
The NASA website (National Aeronautics and Space Administration, 2017) contains fires data from the entire world, in a shape format, which can be processed in ArcGIS. To be suitable to express the intensity of the fire, the data from NASA website was compared to the fire intensity data from the Victorian Government website. Taking into account the value of the brightness of the fire (the unit being the FPR = Fire Radiation Power), the fire intensity data was separate in three categories, this will be explained in Chapter 7.

5.3.7. The river water quality data

In the Latrobe catchment, pollution results from agriculture and urban landuse. The water river pollution is monitored and published monthly by the Department of Environment, Land, Water and Planning and it is available on the website (Department of Environment, Land, Water and Planning, 2017).

5.4. Missing data in the current database

Some of the most important data are the water quality data. The data are recorded one time every month. Even though some monitoring sites have closed in the last 10 years (Department of Environment, Land, Water and Planning, 2017), there are 7 monitoring points in Latrobe catchment with available and reliable water quality data.
The modeling tools allow the user to compute the water quality parameters, using other data such as: elevations, fires and rain intensities, river flow, soil hydrologic properties and evapotranspiration. To be able to use a hydrologic model, the user must calibrate, validate and evaluate it. The first two steps require reliable water quality databases, with water parameters concentrations recorded at least daily. The lack of data leads to a weak calibration of model and the outputs of model will not have a very good accuracy.

The outputs of model depend also of the inputs. If the input data are enough reliable, the outputs have a satisfactory accuracy. The 25 metres DEM was created from the elevation data 5 metres, available on the *Geosciences Australia website*. A better resolution of the DEM (after filling the sinks) would improve the accuracy of the elevation data. These data will be able to take into account smaller flows that could appear in the study area, after a rain. These could carry pollutants in the stream. There could be tens or hundreds of small flows like this, and the computed quantities could be very high, as well as the quantities of pollutants carried in the stream. All these quantities cannot be measured using a 25 m DEM. Using a DEM with a better resolution will definitely improve the accuracy of the outputs.

5.5. Methodology used for modeling and data analysis

eWater starts by creating a project that can have many scenarios. The first step is to upload into the model a file that contains the elevation data (a DEM, for example). Then, the shapefile with the monitoring points must be uploaded. In these points, the user must upload later data related to the river flow, rain, evapotranspiration and water quality data, the latest being used only for calibrating and validating the model.
The data related to the landuse/landcover must be uploaded in the model as a shapefile. *eWater* is very complex: it incorporates rainfall runoff models, constituent generation models and filter models available. The user is able to use various models for every functional unit. The models are characterized by some empirical parameters that can take various values. After assigning certain values to these parameters, a scenario can be saved, as part of a project. The input data can be kept in the project, but changing the empirical parameters, another scenario can be saved. For every set of parameters the model can run and the outputs can be compared with the measured data. The outputs have the same time step (time interval) as the inputs. The goal is to find the best set of empirical parameters, able to show the best correlation between the modeled and the measured data. With this set of parameters the model is considered to be calibrated.
This task is a challenge, because the effect of changed parameters must be analyzed, but also the combined effect of changed parameters must be taken into account.
The next step is to validate and evaluate the model. This can be done using another water quality dataset, then the model must be evaluated applying statistical analyses.

There are many statistical tools used for model evaluation, depending on the model type and the data availability.

eWater is a complex model and its performance can be successfully evaluated with numerical methods such as the correlation coefficient. But, sometimes, a high value of the correlation coefficient does not guarantee that the model fits the data well. Numerical methods for model validation tend to be focused on a particular aspect of the relationship between the modeled and the measured data.

Graphical methods illustrate a broad range of complex aspects of the relationship between the model and the data. A method for evaluating a model is the graphical residual analysis. Still, sometimes residual plots are often difficult to be interpreted due to constraints on the residuals imposed by the estimation of the unknown parameters. Also, sensitivity analysis can be done, in order to understand which parameters are important, and which are not actually contributing to the model performance.

Another thing that must be evaluated is the uncertainty of the output. This cannot be determined by looking at the model residuals. However, the uncertainty of the modeled data will be higher if the value of the parameters' uncertainty is increased. This is also possible when there are many parameters so the combined uncertainty becomes high. A correlation coefficient does not take into account the uncertainty in the model output. Also, a good accuracy of the outputs means that the uncertainty of the input data must be low enough. All these analyses will be discussed in detail in chapter 7.

5.6. Conclusions

In this chapter, the data that was used in this research was reviewed. All the data were available on-line, but still the data are not continuous and many monitoring sites were closed in the last years. The data had to be preprocessed before using in *eWater*, because of the specific requirements of the model. Many files had to be created, in various formats, such as DEM raster, shapefile and csv (comma separated values). The files must contain continuous data, every gap in data leading to errors in the model run. The time step of the modeled data is the same of the time step of the input data. Also, in the points where the model provided the water quality parameters concentrations, the user must have data related to river flow, rain and evapotranspiration. Moreover, the elevation data of the studied area and data that characterize the soil behaviour must be available. Very important are the maps with fires intensities created using fires data from NASA website (National Aeronautics and Space Administration, 2017) and the fire intensities downloaded from the Victorian Government website (Victorian Government, 2017) available for a small area from Victoria.

In this chapter some statistical methods used to evaluate the model performance were listed. There are many statistical methods, but the most suitable and useful, must be chosen, also taking into account the availability of data. The missing data, the gaps in the database, remains the biggest limitation of this research. Only by improving the inputs of the model and the water quality data used for calibration and validation, the model would be very good calibrated and the outputs would have a very good accuracy.

6. MODELING TOOLS: EWATER

6.1. Introduction

The previous chapter reviewed the data and database development. This chapter will discuss the features of the hydrological model used and the steps in creating a project, in order to predict the values of water quality pollutants.

Population growth leads to an increase in water consumption. The quantity and the quality of water are very important, especially in the habited areas. In chapter 5 it was shown that the monitoring campaigns are very expensive. Modeling tools are cheaper solutions compared to monitoring options, used to predict the river water quality parameters. A reliable hydrological model is able to provide accurate information related to the river water quality, in a very short time, helping water management authorities.

There are many hydrological models developed in the world. In the last years, they were improved and the outputs became more accurate. The challenge is to choose the most suitable model, taking into account, in the first instance, the goal that must be achieved. Another criterion is the input data needed for running the model. To provide water quality data, the models need other types of data, which are easier to be collected, but also, they need at least two sets of water quality data for model calibration and validation. Then, the model can be used to produce the water quality parameters for any periods of time in the designed catchment.

In chapter 3, part 2, a review of the most used hydrological models was made. The chapter concluded that the most suitable model for the study area is *eWater*, developed by eWater CRC Australia.

6.2. eWater – the Australian National Hydrological Modeling Platform

eWater Source is a complex instrument able to generate Integrated Water Resources Management (IWRM) combined with water policy and governance capability. This is the reason why *eWater Source* is considered the Australia's national hydrological modeling platform (eWater, 2015a).

It is designed to simulate all aspects of water resource systems to support integrated planning, operations and governance (eWater, 2015a). The model takes into account

natural and anthropogenic pollution and it is able to work at different spatial scales, from the river basin scale, to the urban and regional scales.
Unlike the full version of *Source*, *Source* (public version) does not contain water management and governance capabilities, but it can be applied on a sector, as a water balance tool which forms the basis of development and testing of trans-boundary IWRM water governance approaches in the full version (eWater, 2015b).
eWater Source (public version) can be found on the eWater CRC website. The user must create an account and then they are able to download and install the software. Also, the user has access to the basic training and user guide. Also, the data provided by the developer (the hydrological properties of soils) can be accessed by the user.

***Source* (public version) includes:** Geographic and Schematic Editor, limited in terms of number of nodes (explained in detail in chapter 6.3) and geographic extent, various rainfall-runoff models, constituents generation models, and other types of models such as crop models, environmental demand, time series, function editor, advanced groundwater-surface water interaction tool, function editor for designing custom algorithms, plugin manager for developing new tools and integrating them into *Source*. *Source* supports various settings for Australia, but also for international regions, related to geography, climate and water policy and governance. Figure 6.1 shows that *eWater Source* is widely used all over the world, but the most numerous projects based on it were developed in Australia. A very important feature of *eWater* is its flexibility. It is designed to easily update and customize, and can be configured to the needs of any organisation, taking into account the rapid changes in the science. The model has plugins which are able to help incorporate new capabilities, based on its rational policy and decision framework. *Source* consists in a series of models and tools that have been incorporated into a single flexible and adaptable hydrological model. It also permits users to quickly and easily incorporate existing models, saving time and resources.

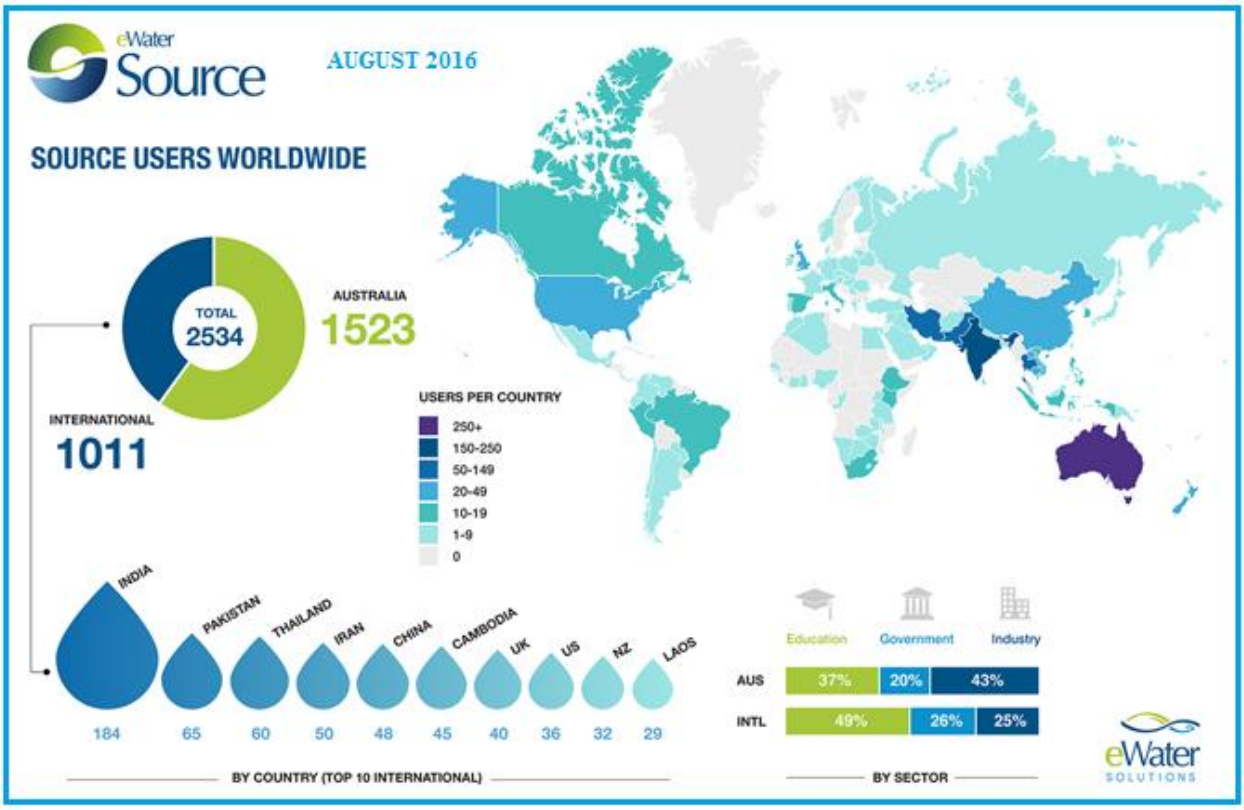


Figure 6.1. The Source users in the world: the highest number of users was recorded in Australia (eWater, 2015a)

The public version of *eWater Source*, which was used for this research, is suitable for integrated water resources management and for decision-making support. It is a fully-featured hydrological, water quality and water balance tool, which was used by Australian government authorities and partners in water resources applications, for water management, plans and policy.

Source is the result of more than 20 years of nationwide research collaboration supported by the Australian government and it was created to be able to adapt at various settings with over 100 applications nationally (eWater, 2016a).

The model interface is very friendly and easy to be used. It is based on a conceptual approach of the river catchment, allowing the users to analyse in a practical way the processes involved.

Source was created to be able to assess the demands in river systems for irrigated agriculture, urban, and industrial, and to apply management options to improve water security. Also, it has analysis options to understand the effects of climate variability and uncertainty and advanced optimisation analysis (see Figure 6.2).

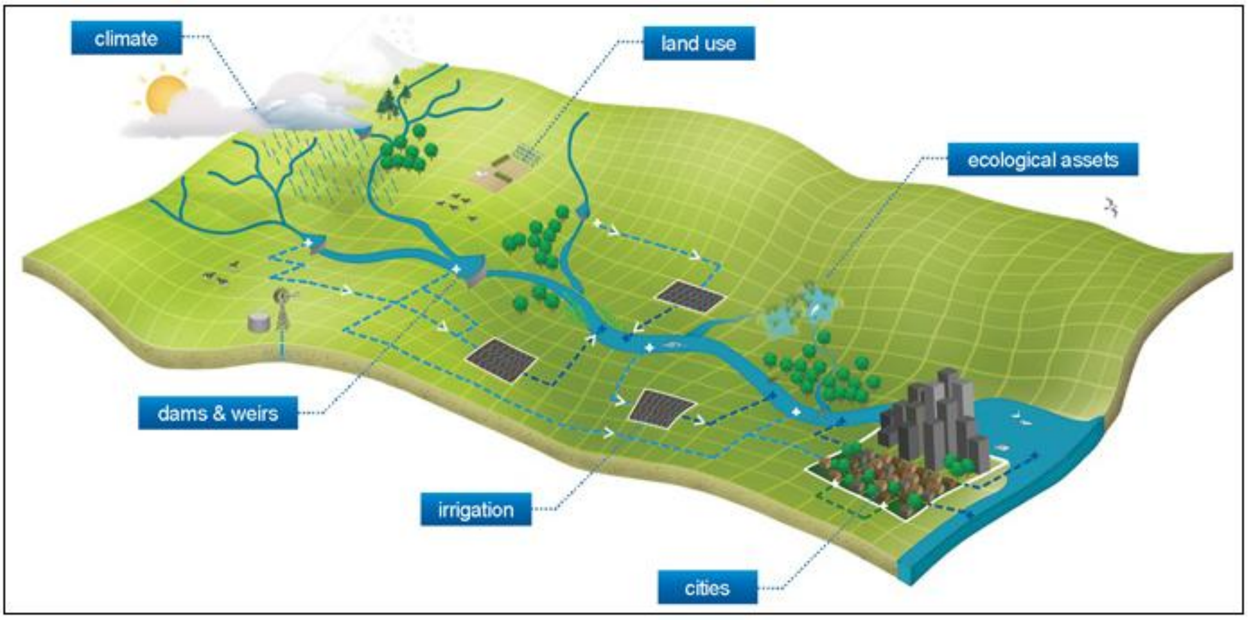


Figure 6.2. A simplified sketch to highlight some of the aspects of eWater Source (eWater, 2015a)

In terms of planning and optimizing the management of water resources, *Source* can reach objectives such as (eWater, 2016b):

- Urban water supply solutions through evaluating new reservoirs, desalination, and stormwater recycling options
- Environmental water demand planning and operational delivery – from sites to basins
- Flood and drought security options analysis and planning
- Catchment land use and water quality improvement.

From a technical and policy perspective, *Source* addresses a variety of important aspects of river management and operations such as: reservoir routing and releases, river flow routing, on-farm storage, groundwater management, groundwater-surface water exchange, sediment, salt and pollutant generation and transport from catchment to rivers.

6.3. Using *eWater Source* to manage catchments

eWater Source enables local knowledge, data and models to be combined with industry best practice to generate effective, transparent catchment management scenarios and options (eWater, 2016c).

The software is able to model the amounts of water and contaminants flowing through a catchment and into major rivers, wetlands, lakes, or estuaries. At the catchment scale, to model properly the water quality, the area of the catchment should be less than 5000 square km.
The outputs of the model can be used to offer clear scenarios and options for making improvements in a catchment.
The input data are: digital elevation data, landuse or soil properties, river flow, rain and evapotranspiration.
Creating a new project and a new scenario is the first step when one uses *eWater*. The scenario is part of the project (Figure 6.3). Making any change in the scenario settings, the user can save it as a different scenario. When the user opens an existing project, any new scenario created will be part of that project.

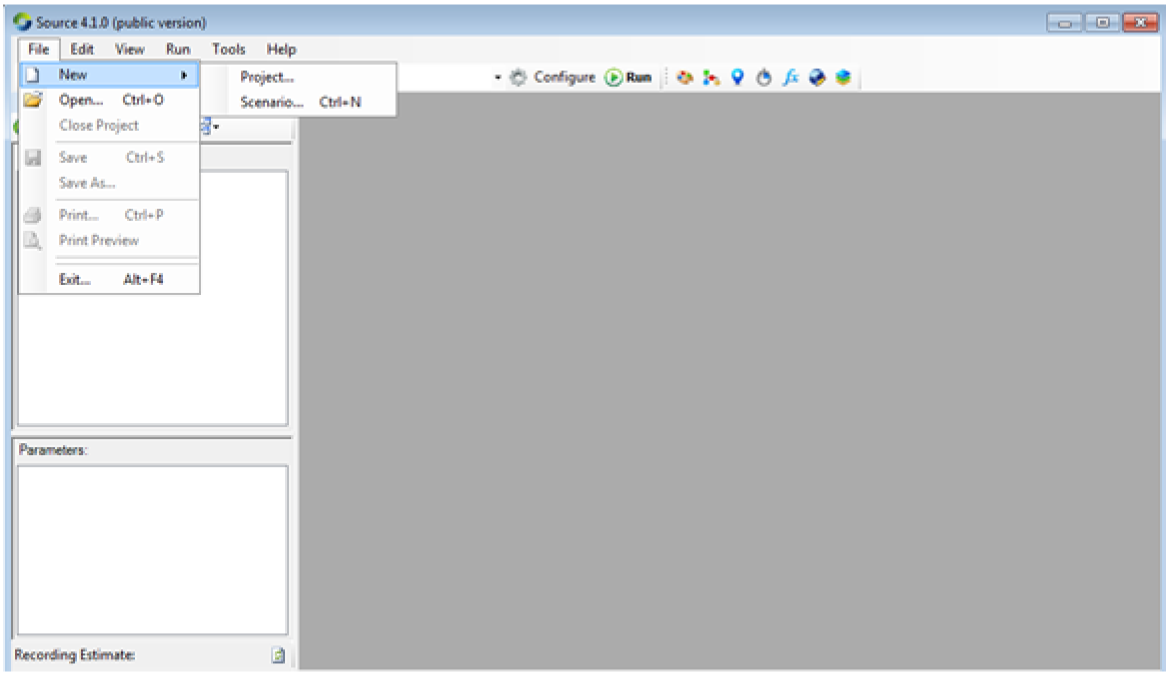


Figure 6.3. Creating a project in eWater

To modify the fundamental features of the project, for example to use another digital elevation model (DEM), a new project must be created. The scenario can be a schematic one, which is typically done from scratch, like a schematic network builder. The user can choose the second option: the geographic wizard scenario (Figure 6.4).

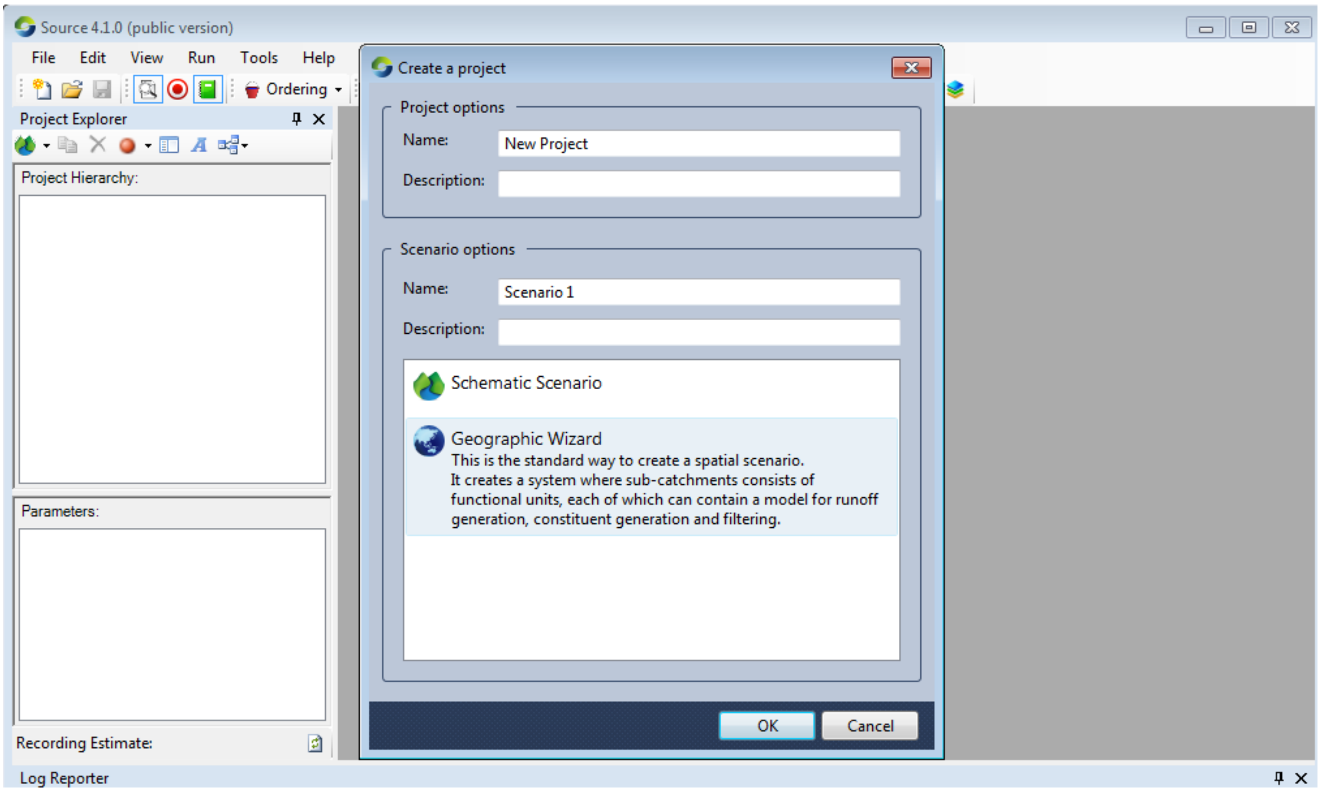


Figure 6.4. Choosing the geographic wizard scenario

The geographic scenario is the standard way to build a spatial scenario, using a DEM. To create a geographic scenario, 4 steps must be followed:

-defining the network and the functional units,

-assigning the rainfall runoff models,

-specify the constituents and choose the constituents generation models for the functional units,

-recording elements and running the scenario.

There are four steps to setting up a project in *eWater Source*, in order to predict water quality parameters.

1. The first step starts with the DEM uploading, as it can be seen in Figure 6.5.

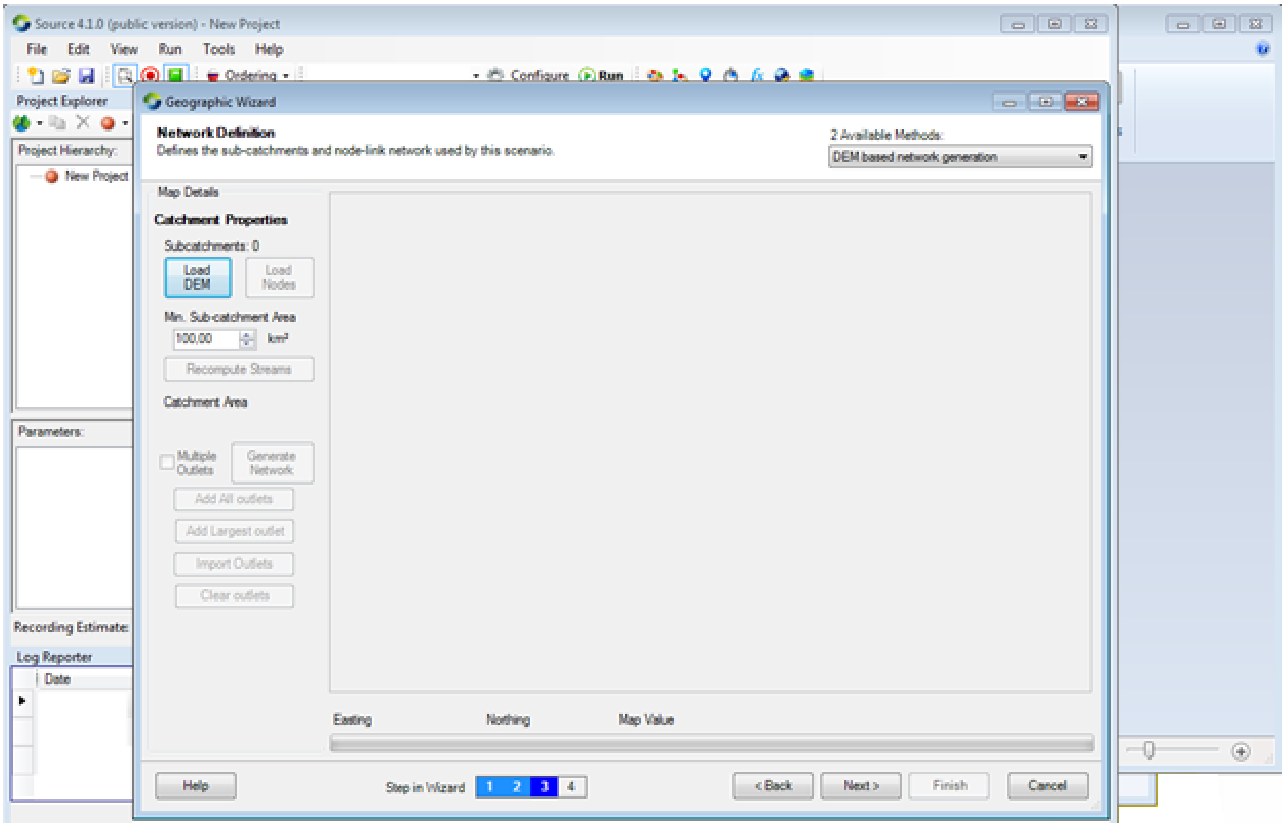


Figure 6.5. The DEM uploading in eWater

Then, the shapefile with the nodes must be also uploaded. The nodes are locations along the river system where the model provides the water quality data based on the input data in the same points. This file is previously created in ArcGIS, using the location data (latitude & longitude) for every node. The number of nodes depends of the data availability. A large number of nodes is preferred, even if the processing time is high (more input data requires more processing time), but the accuracy of the output data is also high. For all these nodes the flow is required and also the water quality data to calibrate and validate the model.

A shapefile with the functional units (FUs) disposing is required at this stage (see Figure 6.6). A functional unit is an area with the same hydrological response, the way a catchment reacts when it is subjected to a rainfall event. Some examples of functional units are: forest, grazing, urban. Based on the flow direction principles, and the minimum area for a sub-catchment, set by the user, the model creates the sub-catchments system.

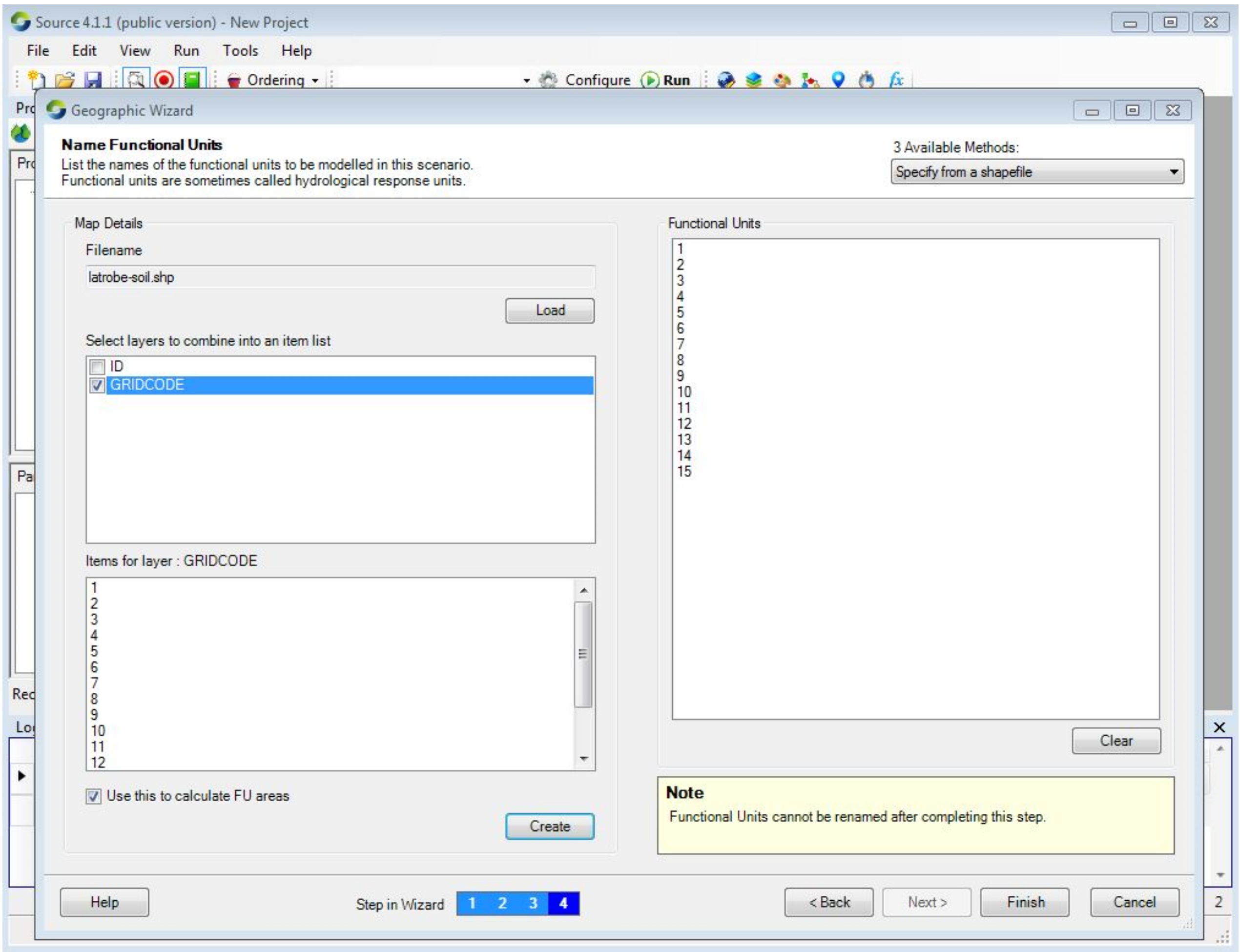


Figure 6.6. Functional Units in eWater

Every sub-catchment consists of more FUs, depending on the soil hydrological properties. *eWater* sets automatically the area and the shape of every FU, within every sub-catchment, and it is able to display the map with the sub-catchments and functional units (Figure 6.7).

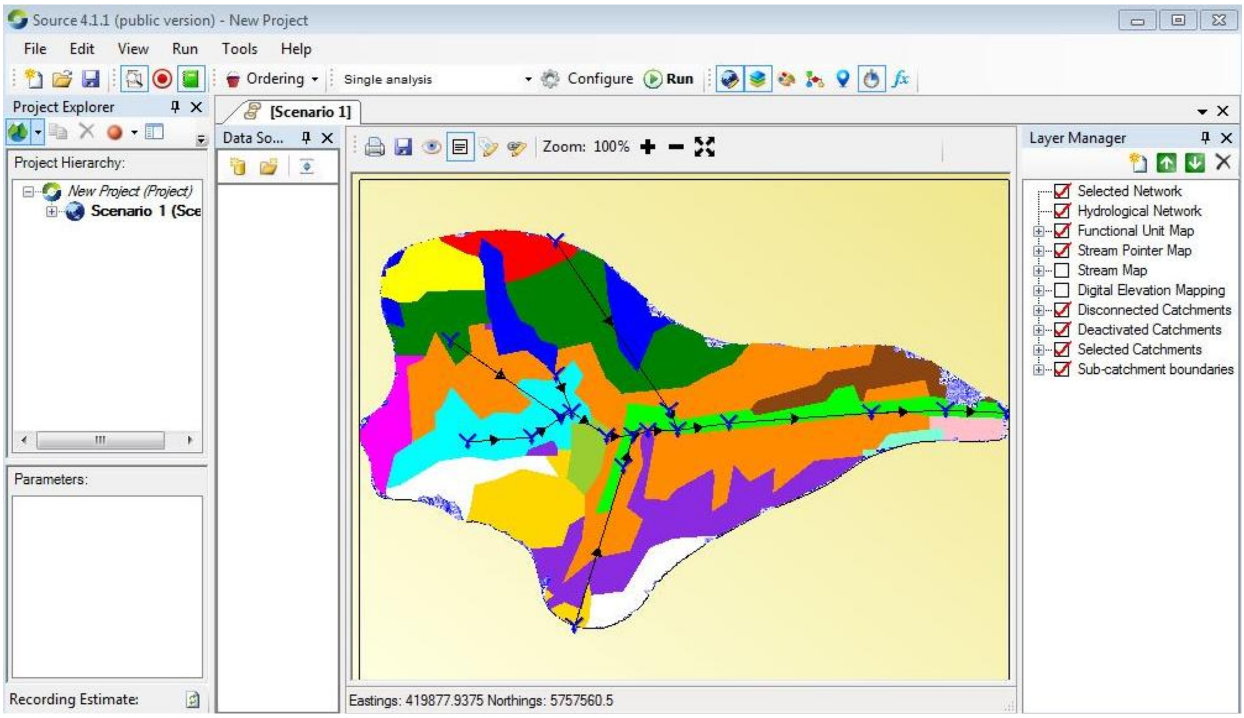
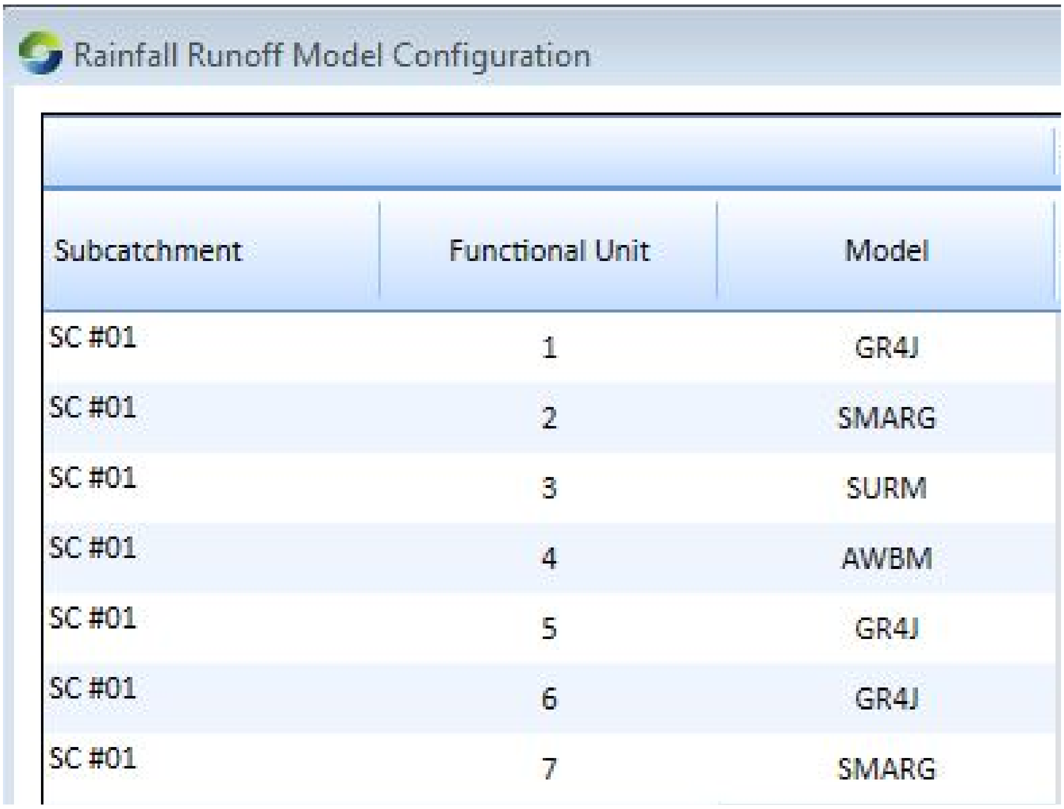


Figure 6.7. The map with the Functional Units for every sub-catchment, in eWater

2. The second step is to specify the rainfall runoff models for every FU, and for every sub-catchment (Figure 6.8). Assigning various rainfall runoff models for various FUs is recommended when the user considers that the FU are very different in terms of hydrological properties of the soil. In a catchment, for water quality purposes, GR4J rainfall runoff model is the most suitable for all types of FUs (eWater, 2016e). The other rainfall-runoff models embedded in eWater (Figure 6.8) are used in other situations such as areas with dams, or are suitable to calculate losses from rainfall for flood hydrograph modeling (AWBM).



Rainfall Runoff Model Configuration

Subcatchment	Functional Unit	Model
SC #01	1	GR4J
SC #01	2	SMARG
SC #01	3	SURM
SC #01	4	AWBM
SC #01	5	GR4J
SC #01	6	GR4J
SC #01	7	SMARG

Figure 6.8. Example of assigning the rainfall runoff models for every FU from sub-catchment 01 in *eWater*

Within this step all the climate inputs (such as evapotranspiration and rainfall data) must be uploaded in the model as Excel comma separated values files, for every FU. This step is completed after the user establishes the parameterisation for every FU.

3. The third step in this process is to define the water quality parameters and to assign the constituent generation models and the filter model. These can be done in a similar way as the rainfall runoff models were defined. Finally, the parameterisation of the constituent generation models has to be set, which means that the user must assign some values for some empirical parameters that are included in the mathematical equations of the constituent generation models. These parameters are specific for a specific site.

4. Recording elements and running the scenario

Before running the model, the user needs to record all the elements of interest. Using the “Record All” button from Project Hierarchy view, all the output variables (such as flow, constituents load, etc.) for every element within the scenario will be recorded.

The Run button will start preparing the output data, and the estimation processing time is displayed in the progress bar. After the scenario run is complete, the Running window can be closed and the output of the model can be viewed either in graph or in map form.

In the Scenario View, clicking on a certain outlet, the corresponding results will be highlighted in the Recording Manager. *eWater* is able to show all the results in a common table and to apply various statistics.

The outputs of the model, run with the parameterisation established, are compared with the measured data in the same points (the nodes in the catchment). Some statistical indicators are able to demonstrate how the modeled data fits with the measured data. This process is repeated until the best parameterisation is found. In particular, the set of parameters which helps the model to provide the best match between the modeled and the measured data must be found.

6.4. Conclusions

The quality of water is a very important issue in the modern society. The monitoring campaigns are very expensive, and cheaper options are the modeling tools.

Choosing a model is a very challenging task. It must be suitable for the established purpose. Also, the user must be aware of the types of data and how must the data be pre-processed. One of the most challenging tasks in research field is to find certain data. This is the reason why the models that use less data are preferred. On the other hand, the accuracy of the output data must be considered. Many models that required little data provide a poor accuracy of the outputs. Other models produce outputs with a very good accuracy, but, unfortunately required too many data. *eWater* in one of the balanced models, because it requires only terrain data, flow, rain and evapotranspiration, and the output data are very reliable. Being able to create various functional units in *eWater*, and parameterising the rainfall runoff, constituent generation models and filters models, the user can consider different surface pollution sources. The values of the parameters can be modified until the output data fit with the measured data. In this way, the set of parameters is established for a certain catchment.

The model can be used in any other catchment, if the user follows the steps to parameterize, calibrate and validate it.

7. DEVELOPMENT, VALIDATION AND EVALUATION OF THE HYDROLOGICAL MODEL

7.1. Introduction

eWater Source is a complex conceptual model, as it was discussed in Chapter 3, able to simulate all aspects of water resource systems. It takes into account natural and anthropogenic pollution and it can be applied at different spatial scales, from the river basin scale, to urban and regional scales.

This model is very suitable to provide the water quality parameters in the chosen catchment, because it is reliable and it requires data that are publicly available.

The model is able to make simulations where the catchment is smaller than 5000 km^2 (Chapter 6), and the processing time depends of the amount of input data. The model can run for simulated period of tens of years, but the processing time can be long (from hours to days depending on the computer resources). To decrease the processing time, a shorter research period can be chosen (one/two years, for example).

To calibrate the model, a set of empirical parameters must be chosen for a specific catchment. To validate a model, the evaluation must be done. The outputs of the model must be compared to the measured water quality data. If the correlation coefficient is high enough, the model can be considered validated for that catchment, based on that set of empirical parameters.

7.2. *eWater* development and parameterisation

The development of the model follows the steps explained in chapter 6, using as inputs the data discussed in chapter 5.

To obtain good output data, many projects can be created as it was explained in Chapter 6, consisting of various scenarios, set the parameters and compare the modeled data with the measured data in the same location and for the same period of time. A project can be built using a set of input data such as DEM (defined in Chapter 5), landuse, climate data and river water flow. Changing the input data, another project can be generated. In the same project, different scenarios can be established by

changing the parameters within the rain runoff model, constituents generation models and filter models (explained in Chapter 6).
The digital elevation model (Chapter 5.3.1), which was uploaded in eWater, in a Geographic Scenario, was processed in ArcGIS (Figure 7.1). This is the first step in creating an eWater project.

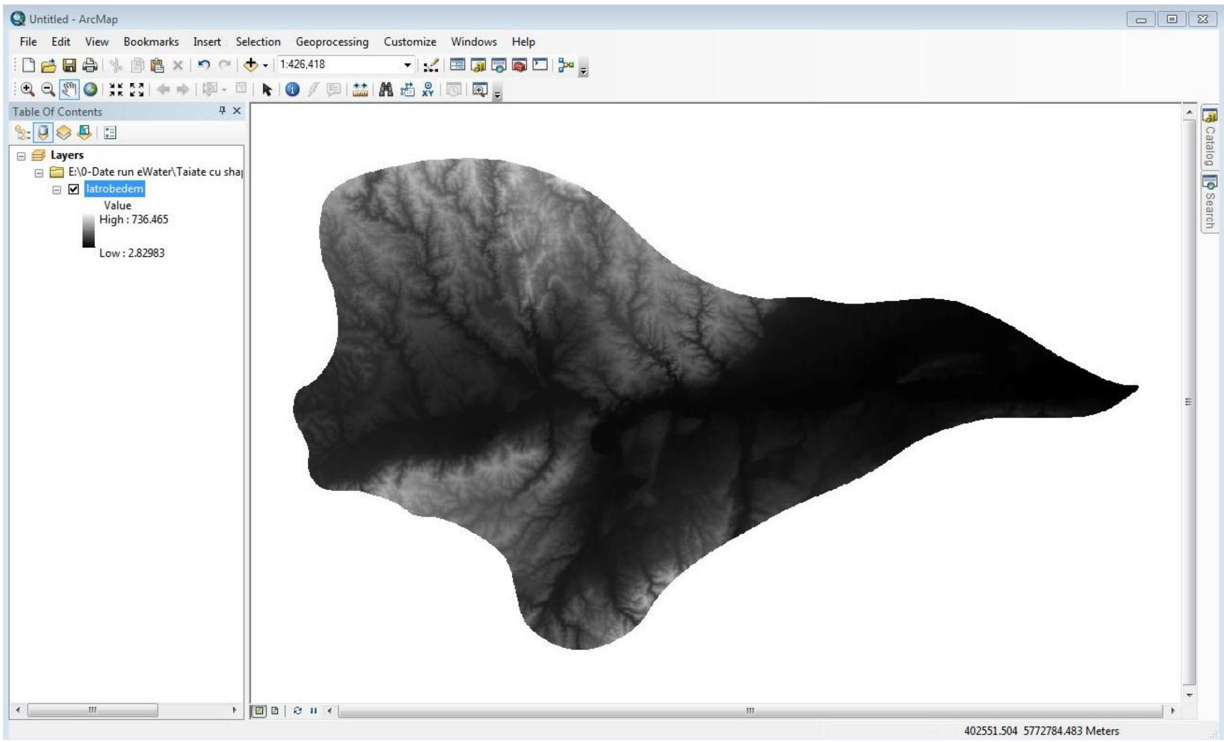


Figure 7.1. DEM processed in ArcGIS

The final outlet, the point in the catchment where the river leaves the catchment, is the lowest point in the catchment. This is the point where water quality parameters which were used to establish the empirical parameters of the model were measured. Taking into account the elevations (which are represented by the DEM data), the model is able to automatically create sub-catchments when the minimum area of a sub-catchment is established. The model was run with a minimum area of the sub-catchment of about 200 square kilometres, as the provider of the model advised. When the minimum area is small, many sub-catchments are created, the model requires many input data and the processing time is very high. On the other hand, establishing a big value for the minimum sub-catchment area, very few sub-catchments are created, the model requires less data, the processing time is very short, but the accuracy of the outputs can be poor. This is why a balanced option must be chosen. Various simulations were performed by creating many projects for the Latrobe catchment, and testing the outputs. Thus, the best option was that the minimum sub-catchment area to be 300 square kilometres. To continue the project building a shapefile with all the monitoring points (7 points in Latrobe catchment) must be uploaded. In all these points, the river water flow, the evapotranspiration, the rain and the water quality parameters for the model validation were required. After running the model, the outputs will be water quality parameters in the same points and with the same time step as the input data (daily data). These 7 points were chosen depending of the data availability. In Figure 7.2., the 7 points saved as a shapefile were uploaded in the Geographic Scenario and the outlet (the red dot on the map).

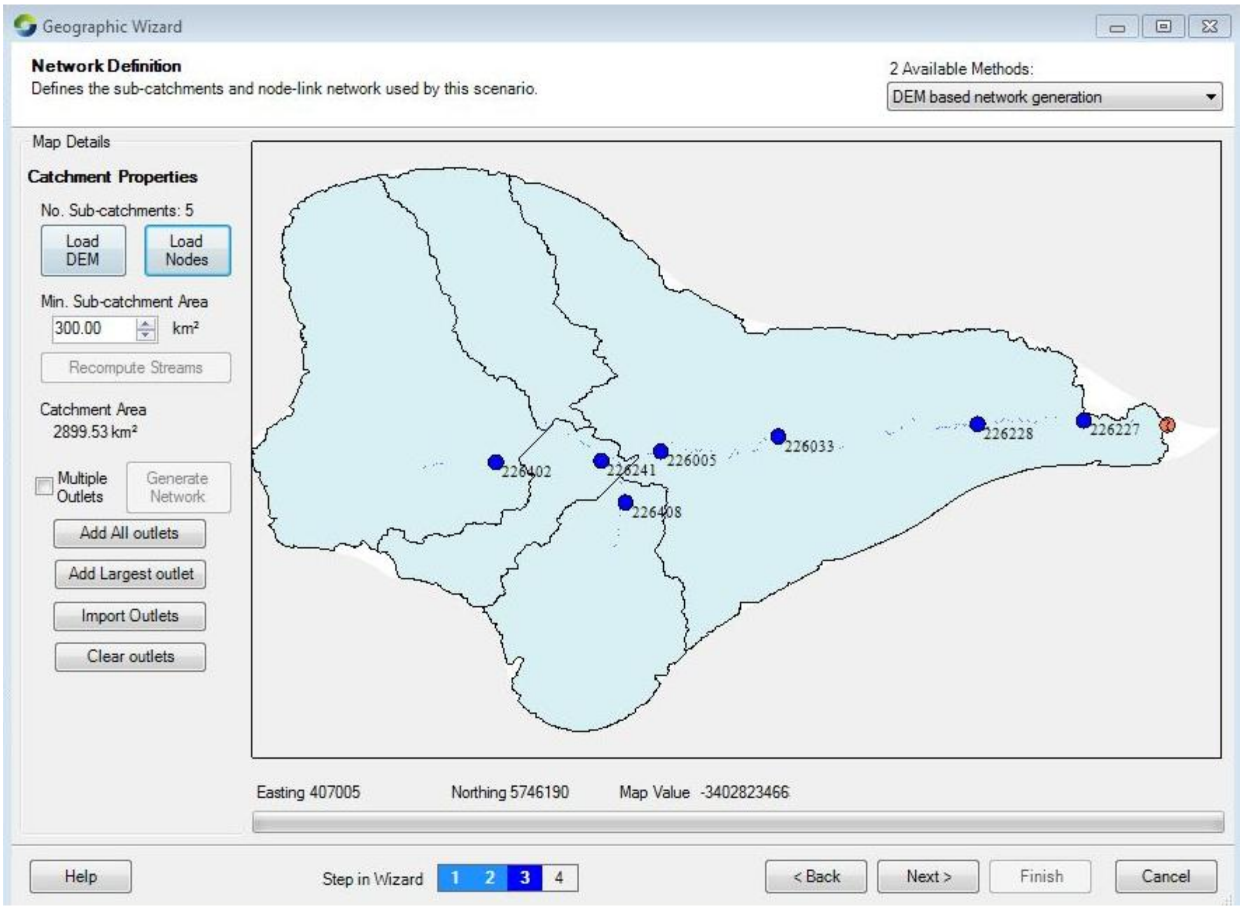


Figure 7.2. Geographic Scenario: DEM and 7 points where the data was collected

In this research 6 classes of landuse were considered, as they can be seen in the Table 7.1.

No.	Landuse type
1	Water
2	Urban
3	Forest
4	Grazing
5	Crops
6	Horticulture

Table 7.1 Landuse types used for this research

The model can be run considering various type of landuse. The landuse can be separated in sub-classes (for example various types of forest), but the amount of input data becomes larger. This means that the processing time is larger, and the accuracy of the output is better.

A more complex situation is when the catchment is burnt. After a bushfire followed by a rain, the area becomes a surface pollution source. The quantity of the pollution transported to the river depends on the intensity of the fire combined with the intensity of the rain.

In this research, the fire data was classified into 3 classes, depending on the brightness of the fire, and the rain data was also divided into 3 classes depending on the quantity of the daily rain, as shown in Table 7.2 and Table 7.3 respectively.

Type (bushfire)	**Brightness (FPR = Fire Radiation Power)**
Low	<350.6
Moderate	350.6 – 401.3
High	>401.3

Table 7.2. Bushfire intensity measured in FPR

Type (rain)	mm/h	**mm/day**
Light	<2.5	<60
Moderate	2.5 - 10	60 – 240
Heavy	>10	>240

Table 7.3. Rain intensity

This classification is adapted using the NASA fire data characteristics and it was made to be used as input data for *eWater* model. According to the Table 7.4, there are 9 possible combinations between fire intensity and rain intensity.

No.	Fire Intensity	Rain Intensity	Combination classes
1	LOW	LIGHT	**LL**
2	LOW	MODERATE	**LM**
3	LOW	HEAVY	**LH**
4	MODERATE	LIGHT	**ML**
5	MODERATE	MODERATE	**MM**
6	MODERATE	HEAVY	**MH**
7	HIGH	LIGHT	**HL**
8	HIGH	MODERATE	**HM**
9	HIGH	HEAVY	**HH**

Table 7.4. The combination obtained from 3 classes of fire intensity and 3 classes of rain intensity

For example when the fire intensity is HIGH and the rain is LOW, the combination which resulted is HL, or if the fire is MODERATE and the rain is HIGH, the result is MH.
The fire and rain data can be divided into more than 3 classes, but the number of combination between them will be much greater, so the complexity of the input data will be very high. This means a lot more parameters that must be set and longer processing time. The good thing is that the accuracy of the modeled data will be higher. If less than 3 classes are chosen, there is less data, the processing time will be shorter, but the accuracy of the model outputs will be very low. A balanced option can be found after many tests.
To establish the types of landuse used as input data in *eWater*, the same approach was used. Using many types of landuse gives the opportunity to set empirical parameters for each of them. This will increase the quantity of data and the processing time. Establishing very few types of landuse will decrease the processing time, but it will also decrease the accuracy of the output data. Analysing the results of tens of tests, the balanced option can be found. In this research 6 types of landuse were established

(Table 7.1). Bushfires can occur anywhere in the Latrobe catchment. To take into account the characteristics of every landuse that is burnt, the model has to be parameterized different for any type of burnt landuse. The landuse input data must contain the 6 landuse classes for the areas which are not burnt, and the combination between land use, fires intensity and rain intensity, for the burnt surfaces. In terms of pollution after bushfires, there is a big difference between burnt forest and other burnt landuse. In this research 2 types of burnt landuse were considered: forest and non-forest (grazing). In Table 7.5 are displayed all the combinations which are the total number of functional units (FUs) in the studied catchment, 18 FUs in this case.

No.	Combination-Fire and Rain Intensities	Forest/Grazing	FU (Functional Units)
1	LL	FOREST	**LLF**
2	LL	GRAZING	**LLG**
3	LM	FOREST	**LMF**
4	LM	GRAZING	**LMG**
5	LH	FOREST	**LHF**
6	LH	GRAZING	**LHG**
7	ML	FOREST	**MLF**
8	ML	GRAZING	**MLG**
9	MM	FOREST	**MMF**
10	MM	GRAZING	**MMG**
11	MH	FOREST	**MHF**
12	MH	GRAZING	**MHG**
13	HL	FOREST	**HLF**
14	HL	GRAZING	**HLG**
15	HM	FOREST	**HMF**
16	HM	GRAZING	**HMG**
17	HH	FOREST	**HHF**
18	HH	GRAZING	**HHG**

Table 7.5. The number of FU resulted from the combination between fire intensity, rain intensity and type of landuse which was divided in forest and grazing

As an example, when a FOREST area was burnt by a fire with HIGH intensity and it was followed by a HEAVY rain, the combination obtained would be HHF (HIGH fire intensity, HEAVY rain, FOREST burnt area); or if a GRAZING area was burnt by a fire with LOW intensity followed by a LIGHT rain, the combination would be LLG (LOW fire intensity, LIGHT rain, GRAZING burnt area).

For the areas which were not burnt, the same landuse classes were kept (Table 6.1).

If the landuse is uploaded as a shapefile, *eWater* automatically calculates the area of every FU in the sub-catchment, and it displays the map with the sub-catchments as a raster (Figure 7.3).

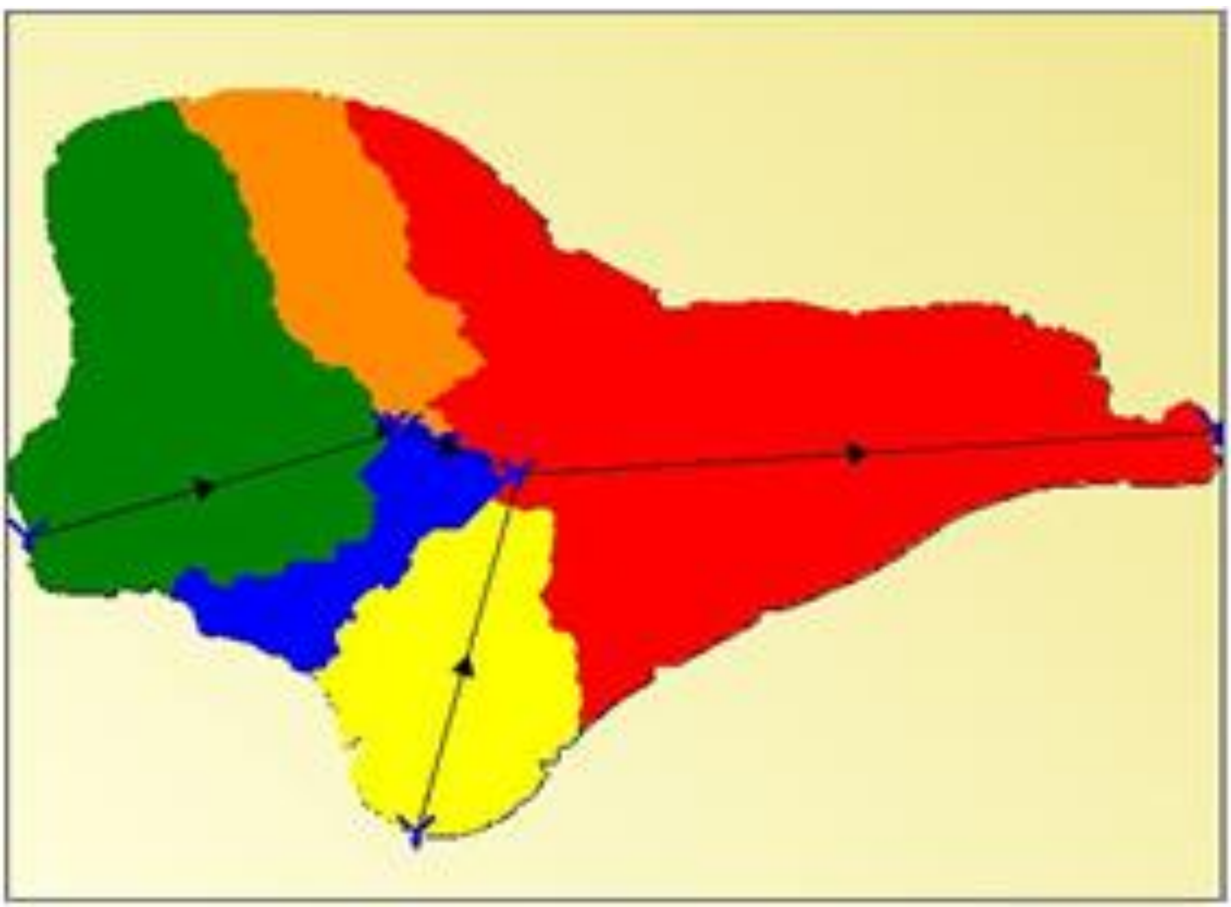


Figure 7.3. eWater Source displaying the sub-catchments in raster format

7.3. The calibration of the hydrological model

7.3.1. The parameterisation and calibration of the rainfall runoff model

At this stage, the rainfall runoff model must be established for every combination of FU for each sub-catchment. Then, the climate inputs (such as evapotranspiration and rainfall data) must be uploaded in the model as csv (comma separated values) files, for every FU.

GR4J rainfall runoff model was chosen for this research because it is suitable for water quality purposes in a catchment with various landuse (as it was explained in chapter 6.3, second step - setting up a project in *eWater*). This model is embedded in *eWater*. It is a daily lumped rainfall–runoff model belonging to the family of soil moisture accounting models. There are four empirical parameters that must be calibrated: X1, X2, X3, X4. These parameters are considered empirical because their values depend on the characteristics of the site: soil properties, landuse, slope, vegetation, and other features which may impact on the generation, transport, filter and losses of the pollutants that flow to the river.

X1 = maximum capacity of water stored in the soil (mm);

X2 = groundwater exchange coefficient (mm);

X3 = one day ahead maximum capacity of the routing store (mm)

X4 = time base of unit (time step in hours) (Perrin et al., 2003)

Higher values of X1 increase soil moisture, higher values of X2 increase streamflow, X3 controls the discharge of baseflow, higher values of X4 delay, attenuate the hydrograph (Commonwealth Scientific and Industrial Research Organisation, 2010).

The default, lower and higher values for these 4 parameters are displayed in Table 7.6.

Name	Default	Min	Max	Units
X1	350	1	3000	mm
X2	0	-27	27	mm
X3	150	1	660	mm
X4	40	1	240	h

Table 7.6. Parameters of the GR4J model (Commonwealth Scientific and Industrial Research Organisation, 2010)

Different values must be assigned to the parameters, and the output must be analysed. Every parameter contributes to the change of the output. Also, their combination impacts on the values of the output.

To establish the values of the empirical parameters, a project must be created, and the outputs of the model must be compared to the water quality parameters recorded in point 7 (the outlet), because it is the most downstream point of the catchment. In this way, the empirical parameters must be suitable for the whole catchment. Then, one by one the parameters must be changed, and the outputs of the model must be analysed. When the modeled values of the water quality parameters are very well correlated with the measured data, for a set of empirical parameters that set of parameters will be suitable for the catchment.

After 127 projects created in *eWater* (evaluating the results of the simulations), the values for the rainfall runoff model parameters, found in this research to be the most suitable for Latrobe catchment can be viewed in Table 7.7.

Type of Land/Empirical Parameters	X1 (mm)	X2 (mm)	X3 (mm)	X4 (h)
WATER	3000	0	150	24
URBAN	400	-25	500	24
FOREST	2400	-24	400	24
GRAZING	1500	-23	300	24
CROPS	1600	-26	250	24
HORTICULTURE	1300	-22	200	24
LLF	220	-21	140	24
LLG	240	-20	130	24
LMF	150	-6	110	24
LMG	270	-5	100	24
LHF	280	15	40	24
LHG	300	16	30	24
MLF	70	-16	130	24
MLG	90	-15	120	24
MMF	100	-1	100	24
MMG	120	0	90	24
MHF	130	20	30	24
MHG	150	21	20	24
HLF	20	-11	120	24
HLG	40	-10	110	24
HMF	50	4	90	24
HMG	70	5	80	24
HHF	80	25	20	24
HHG	100	26	10	24

Table 7.7. The empirical parameters of the rainfall runoff model for the Latrobe Catchment

7.3.2. Calibration of the constituents generation model

The next step is to configure the constituents (water pollutants). This research is focused on total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP), because they are important parameters for evaluation the water quality and this data was available.

To improve the accuracy of the model, the option “Marker” which is available in eWater must be selected. This option allows the model to consider the pollutants traveling through the river network, taking also into account their decay or losses, which are governed by physical laws.

A constituent generation model must be chosen from a list of models embedded in eWater, and the empirical parameters must be established.

In this research the EMC/DWC constituent generation model was chosen. The Event Mean Concentration (EMC)/Dry Weather Concentration (DWC) model uses a certain concentration to a functional unit. The EMC value is the sediment generated by a quick flow, and DWC is related to the base flow. This option was chosen after all the constituents generation models available were tested.

For each FU in a sub-catchment, the model EMC/DWC takes into account a settled value of the concentration of sediment (in mg/L). EMC and DWC can sometimes differ by more than an order of magnitude (Chiew and Scanlon, 2002). EMCs and DWCs vary with land-use, soil type, slope, climate and management practices in the catchment area. The most important advantage of the EMC/DWC model is the fact that it has two empirical parameters (EMC and DWC) which are able to define the properties of the terrain. These parameters are dimensionless. The final EMC parameters for TSS, TN and TP are reported in Table 7.8.

	Landuse/EMC Parameters	EMC for TSS	EMC for TN	EMC for TP
1	WATER	3	1.1	0.1
2	URBAN	67	1.7	0.12
3	FOREST	80	1.9	0.18
4	GRAZING	184	2.1	0.24
5	CROPS	131	1.6	0.13
6	HORTICULTURE	305	5.3	0.93
7	LLF	250	5.8	0.8
8	LLG	220	5.5	0.6
9	LMF	300	6.3	1.2
10	LMG	260	6.0	1.0
11	LHF	340	6.9	2.0
12	LHG	310	6.6	1.8
13	MLF	320	6.4	1.1
14	MLG	270	6.2	0.9
15	MMF	370	6.8	1.9
16	MMG	315	6.5	1.7
17	MHF	400	7.5	2.7
18	MHG	360	7.3	2.5
19	HLF	350	7.0	1.6
20	HLG	325	6.7	1.4
21	HMF	390	7.4	2.6
22	HMG	370	7.2	2.4
23	HHF	450	8.1	3.1
24	HHG	410	7.9	2.9

Table 7.8. EMC empirical parameters for TSS, TN and TP for the Latrobe Catchment

The final DWC parameters for TSS, TN and TP are reported in Table 7.9.

	Landuse/DWC Parameters	DWC for TSS	DWC for TN	DWC for TP
1	WATER	0.3	0.11	0.01
2	URBAN	6.7	0.17	0.012
3	FOREST	8.0	0.19	0.018
4	GRAZING	18.4	0.21	0.024
5	CROPS	13.1	0.16	0.013
6	HORTICULTURE	30.5	0.53	0.093
7	LLF	25.0	0.58	0.08
8	LLG	22.0	0.55	0.06
9	LMF	30.0	0.63	0.12
10	LMG	26.0	0.6	0.1
11	LHF	34.0	0.69	0.2
12	LHG	31.0	0.66	0.18
13	MLF	32.0	0.64	0.11
14	MLG	27.0	0.62	0.09
15	MMF	37.0	0.68	0.19
16	MMG	31.5	0.65	0.17
17	MHF	40.0	0.75	0.27
18	MHG	36.0	0.73	0.25
19	HLF	35.0	0.7	0.16
20	HLG	32.5	0.67	0.14
21	HMF	39.0	0.74	0.26
22	HMG	37.0	0.72	0.24
23	HHF	45.0	0.81	0.31
24	HHG	41.0	0.79	0.29

Table 7.9. DWC empirical parameters for TSS, TN and TP for the Latrobe Catchment

7.3.3. The parameterisation and calibration of the filter model

The filter model embedded in *eWater* takes into account various physical processes which lead to decrease the quantity of pollution in the river, calculating it for every type of pollutant.

After tens of tests, the filter model chosen in this research was The Percentage removal model. It is a simple linear multiplier model that has a constant removal coefficient applied to the constituent load. The model is implemented as an equation in the *eWater* software. Base-flow and quick-flow can have different percentage removal coefficients which must be established by the user, as empirical parameters. The value ranges from 0 to 100, and represents the percentage of load removed. The base-flow and quick-flow parameters for TSS, TN and TP are displayed in Tabel 7.10.

FILTER MODEL PARAMETERS	TSS (%)	TN(%)	TP(%)
BASE-FLOW PARAMETER	30	10	8
QUICK-FLOW PARAMETER	20	7	5

Table 7.10. The percentage of base-flow and quick-flow load removed for TSS, TN, and TP

7.4. The validation and evaluation of the hydrological model

7.4.1. Water quality Database

eWater project was calibrated using the water quality data measured in P7 (point7 from the catchment).

To validate the model, the modeled data must be compared to the measured data in P1 to P6 (all the other six points available). The output of the model is daily data. The measured data was recorded one time every month. To make the comparison, the user has to calculate the monthly average for the modeled data. There were 32 monitoring points in the Latrobe catchment, but in this research the data recorded in seven points were used, for the period 2008 – 2016. They were selected based on the reliability of the data. Many monitoring points do not have continuous data. Also, after a short analysis, the data shows inaccuracies and must be excluded from the database. In

Figure 7.4, the TSS data from the whole year 2009 had two values, so this data is unlikely to be correct.

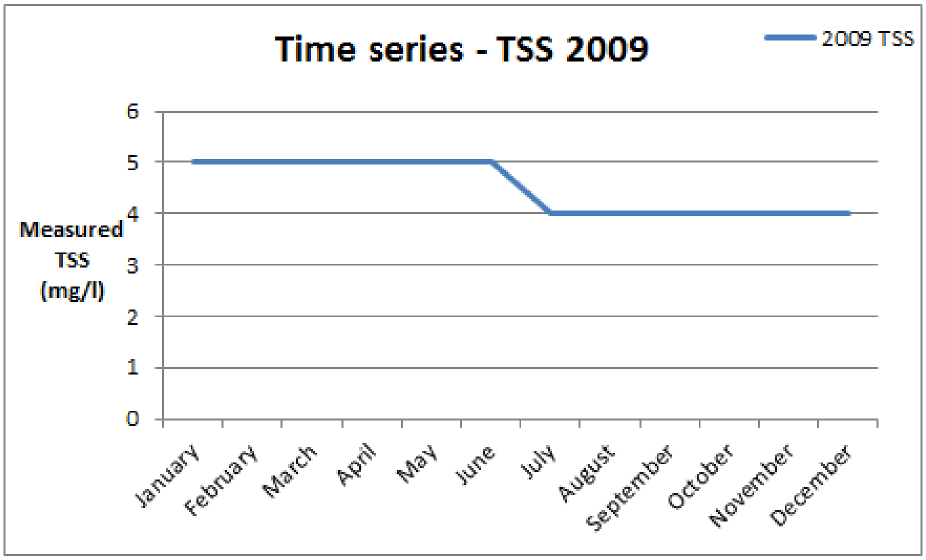


Figure 7.4. Example of inaccurate data: TSS for year 2009

Another example is Figure 7.5, where the TSS values are the same for four or five months. It is practically impossible for two water samples collected from the same point to have exactly the same TSS value. So, the same value for a pollutant in the river for about four successive months would be considered erroneous. A behaviour like this can be explained based on the human errors that can appear when a monitoring operation on large area is developed.

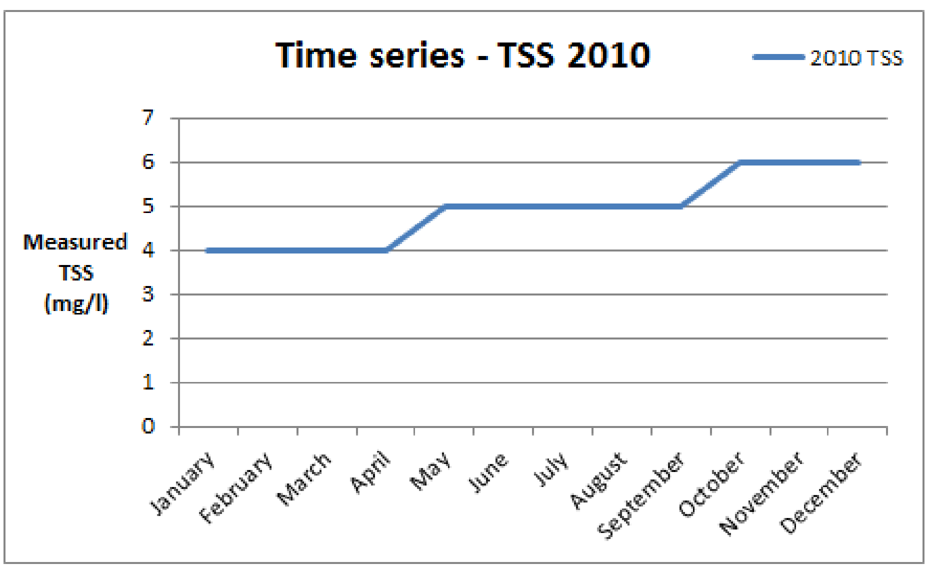


Figure 7.5. Example of data with unusual behaviour: TSS for year 2010

Comparing to the turbidity data, TSS should have a similar trend. An example of TSS measured data which has an opposite behaviour against measured turbidity is shown in Figure 7.6. and 7.7.

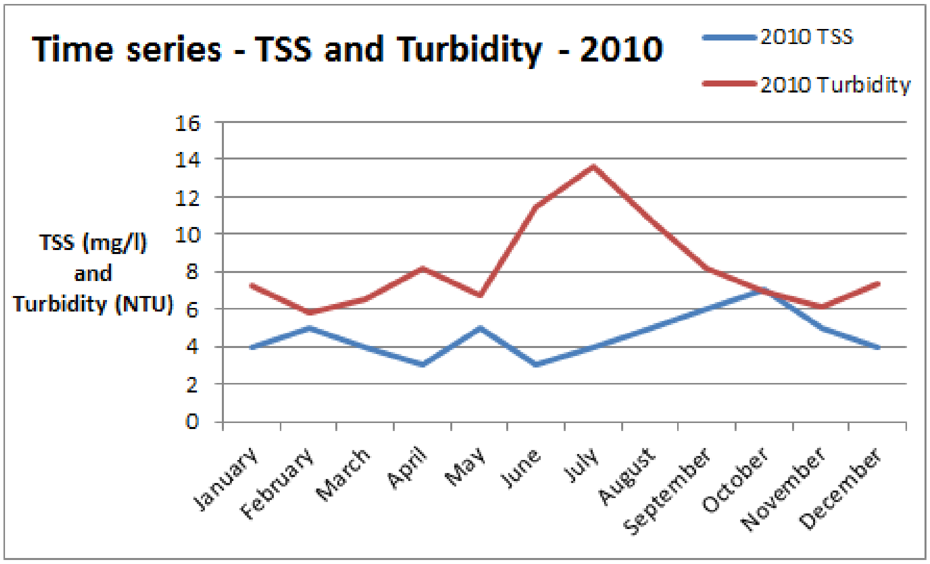


Figure 7.6. Example of data with opposite behaviour: TSS and turbidity, 2010

A similar example is displayed in Figure 7.7:

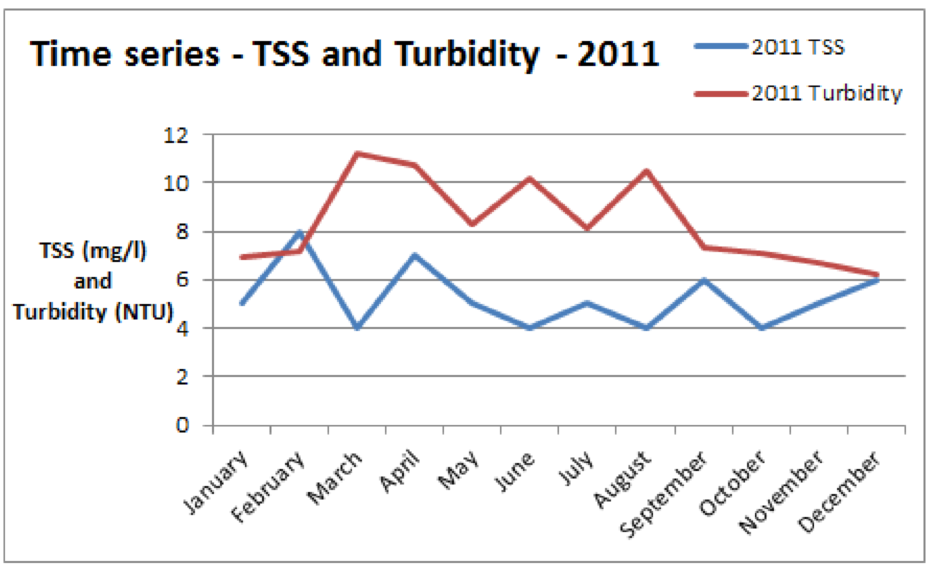


Figure 7.7. Example of data with opposite behaviour: TSS and turbidity, 2011

Also, another case is when turbidity shows higher values which are explained on the basis that in 2009 there were bushfires in the catchment (Figure 7.8).TSS have low values, and do not show a difference between a year with bushfires and other years, and there is no similar trend in data.

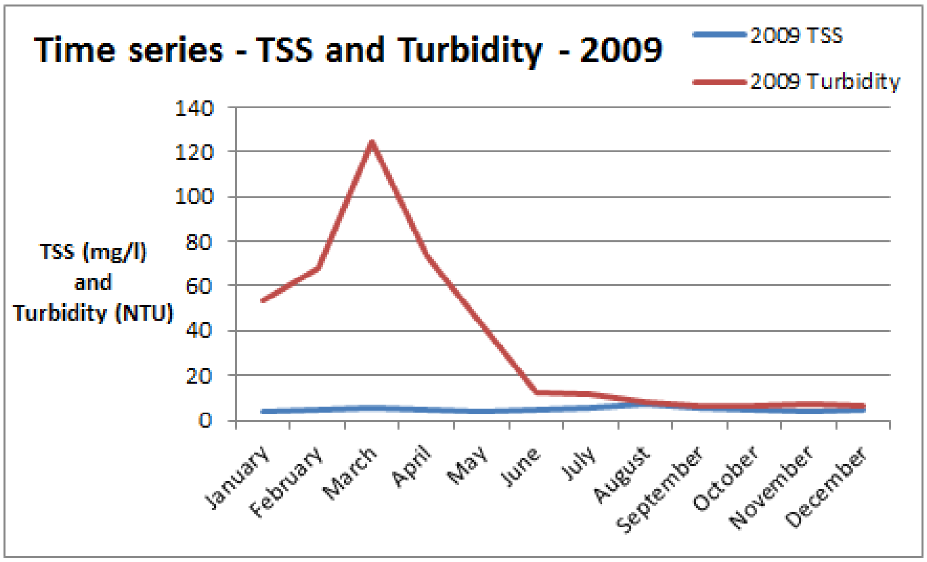


Figure 7.8. Higher levels of turbidity due to bushfires; TSS data does not show this phenomenon

Finally, from 32 monitoring points, seven monitoring points were selected, with reliable and continuous data. The analysis of this data shows good correlations between the modeled and the measured data. In Figure 7.9, the Latrobe catchment is displayed, showing the landuse and the monitoring points, where *eWater* was run.

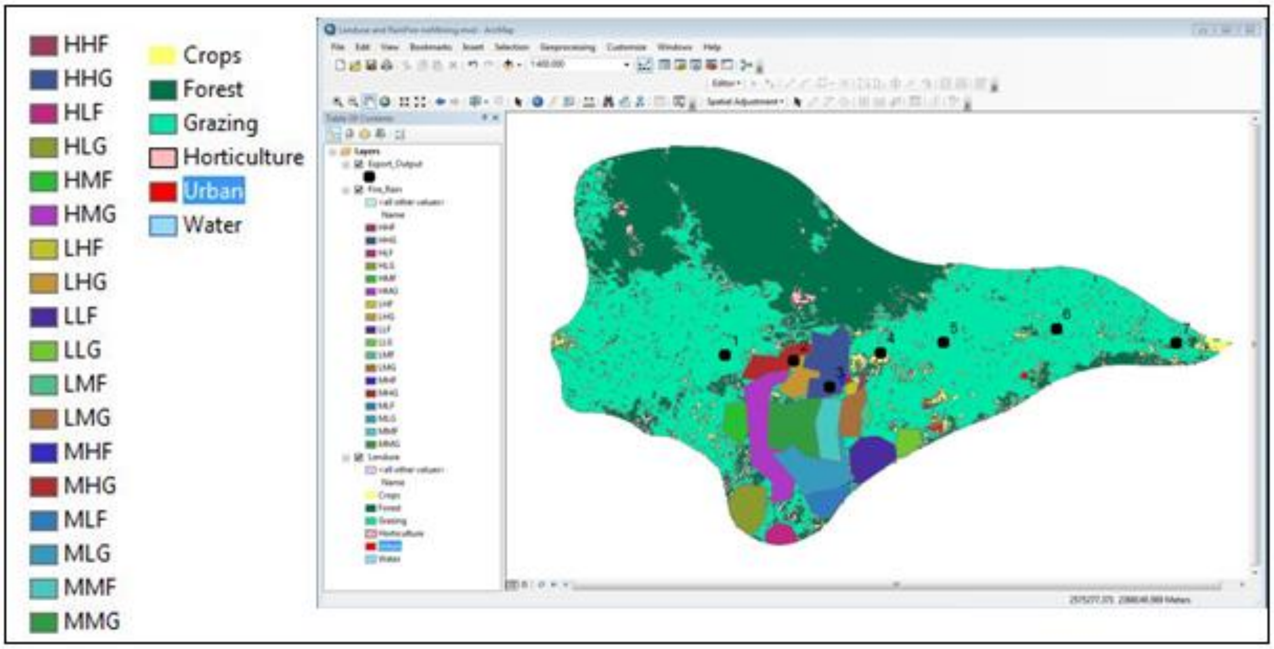


Figure 7.9. The landuse and the monitoring points in the Latrobe catchment

7.4.2. Validation and evaluation of the model for TSS

The data showed higher levels of TSS after rain, and the TSS values are very large after a bushfire followed by rain.

In all monitoring points, the correlation coefficients had values higher than 0.7, so the model, with this parameterisation, is able to reasonably predict the TSS pollution. The trend for the modeled and the measured matches. An example for 2009, of correlation between the modeled and measured TSS for the monitoring Point 1, is presented in Figure 7.10. The correlation coefficient is 0.8833, so the model is able to well predict the pollution in this location.

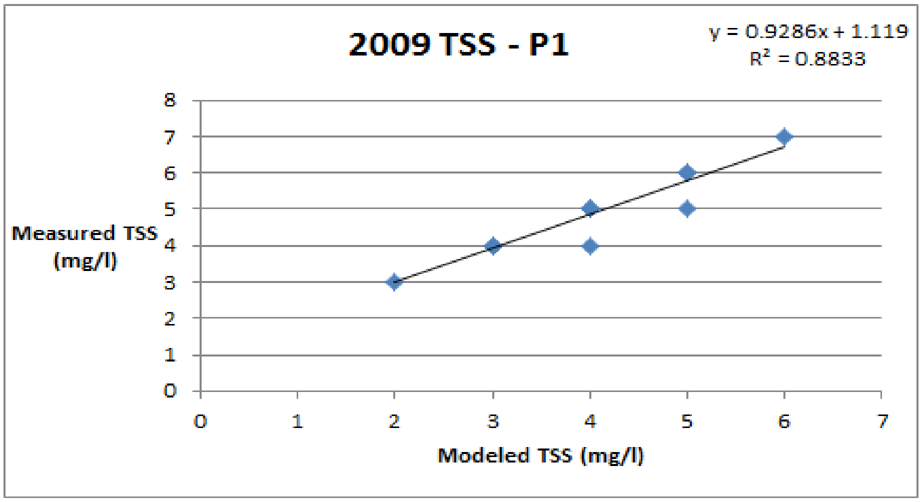


Figure 7.10. The correlation between the TSS modeled and measured for Point 1, 2009

Also, the measured and modeled data showed similar trend, the main difference was the fact that the model predicted slight higher values compared to the measured values, so it overestimated (see Figure 7.11)

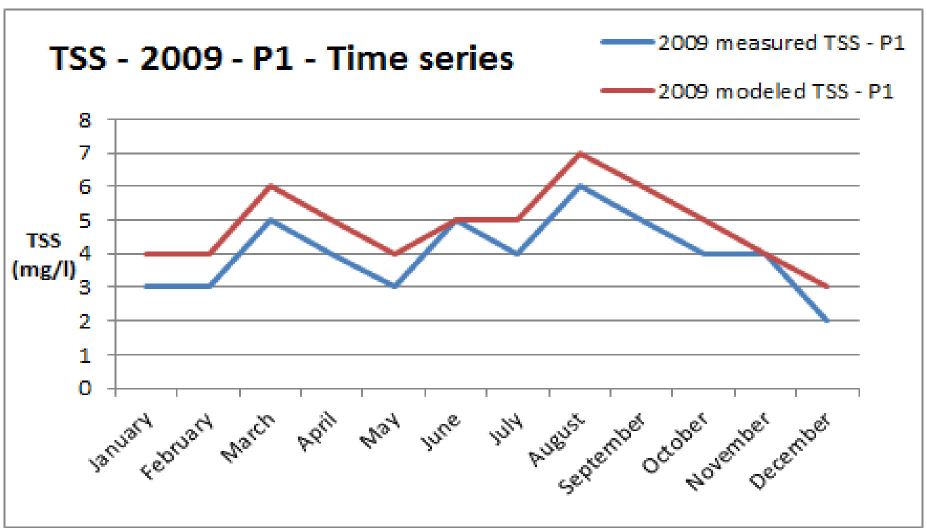


Figure 7.11. Time series for TSS, for both measured and modeled data, in Point 1, 2009

Comparing the measured data in P1 from 2008, 2009 and 2010, the values are very close. 2009 is the year when there were bushfires in the Latrobe catchment. The measured TSS concentrations are displayed in figure 7.12. The concentrations in February-April 2008, 2009 and 2010 are less than 7 mg/l. This means that the bushfires did not affect the water quality in Point 1. The area, from which the water is collected in

Point 1, was not burnt. So, the pollution resulting from bushfires was transported towards Point 2.

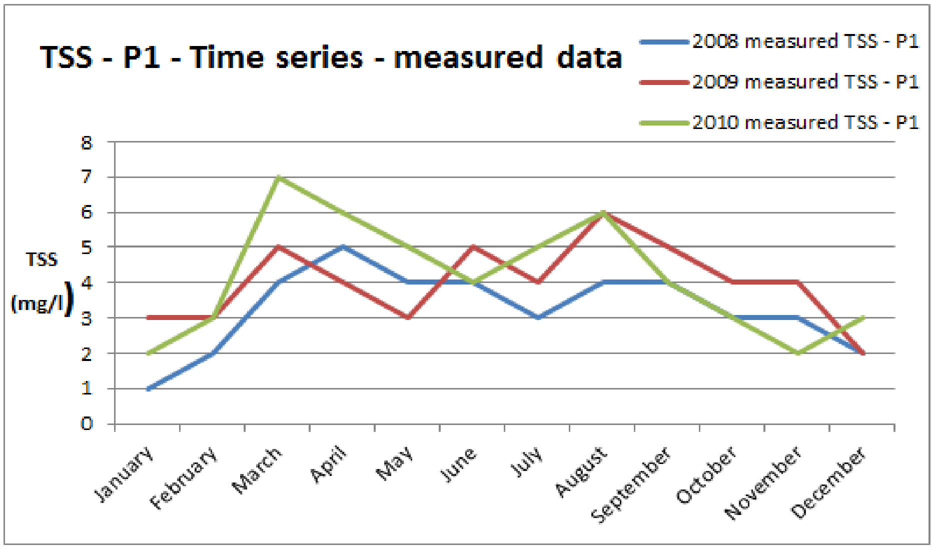


Figure 7.12. Time series for measured TSS in 2008, 2009, 2010, for Point 1

The same behaviour can be seen in Figure 7.13 for TSS modeled data in P1, for 2008, 2009, 2010.

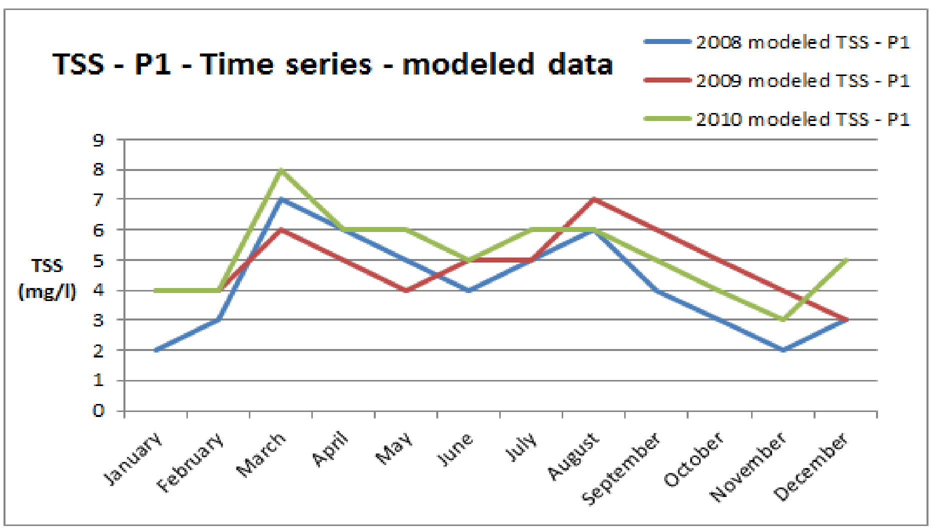


Figure 7.13. Time series for modeled TSS in 2008, 2009, 2010, for Point 1

The correlations between the modeled and measured data are very good for Point 2, as well. Figure 7.14, displayed the correlation for 2008.

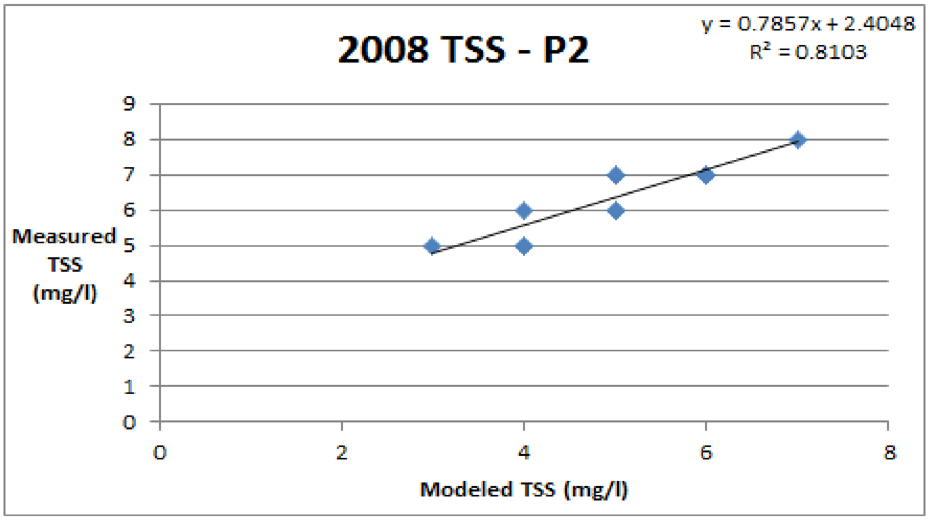


Figure 7.14. The correlation between the TSS modeled and measured for Point 2, 2008

The trends are almost identical for both measured and modeled data for Point 2, 2008. It can be noticed the same behaviour: the model overestimated (Figure 7.15).

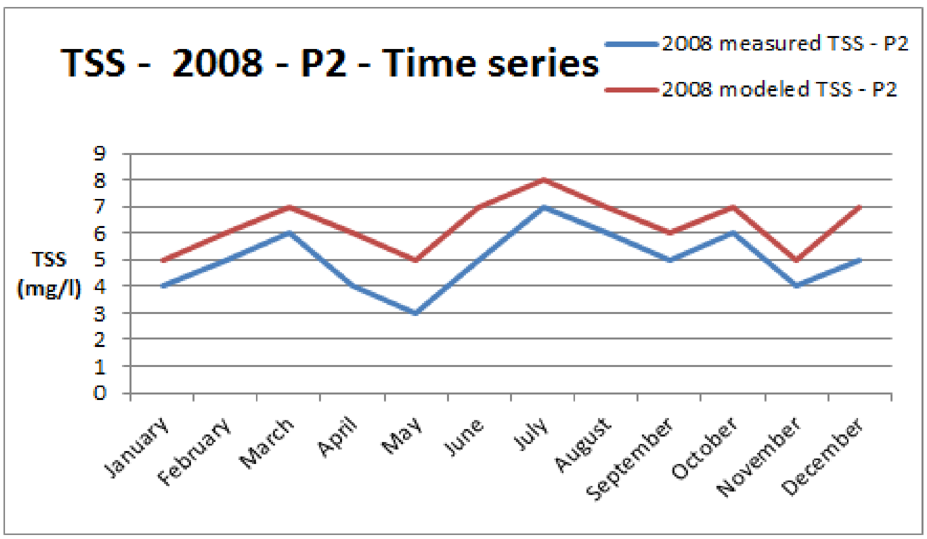


Figure 7.15. Time series for TSS, for both measured and modeled data, in Point 2, 2008

In 2009, the correlation coefficient between the modeled and the measured data is over 0.8, which means that the model is able to predict very good the pollution resulted from bushfires (Figure 7.16)

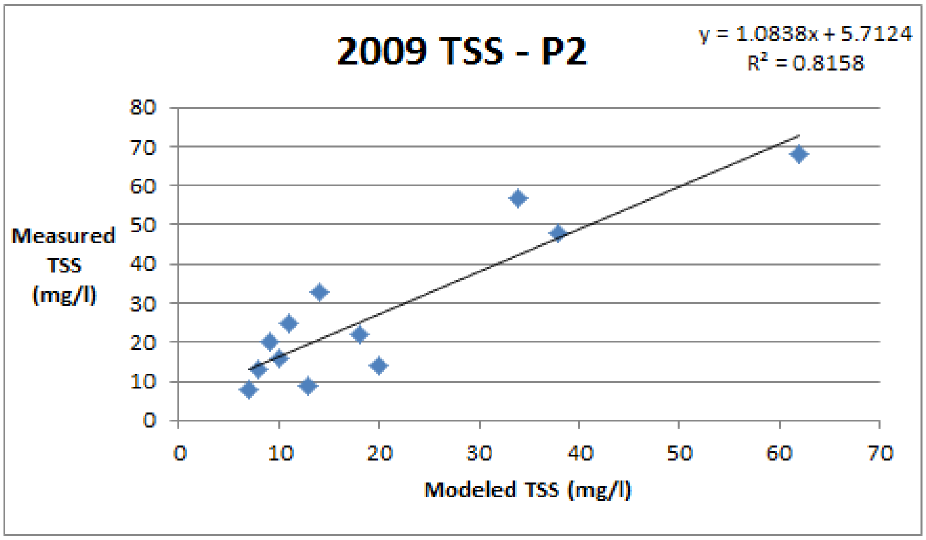


Figure 7.16. The correlation between the TSS modeled and measured for Point 2, 2009

Figure 7.17 showed the trend of the measured and modeled data. The high TSS peak in March 2009, resulted from bushfire pollution, is well expressed in the modeled data. Between March and December 2009, both the measured and the modeled data reduced, but the modeled data had a smoother decline compared to the measured data, which means that there are some other factors that impact the sources and the sinks of TSS.

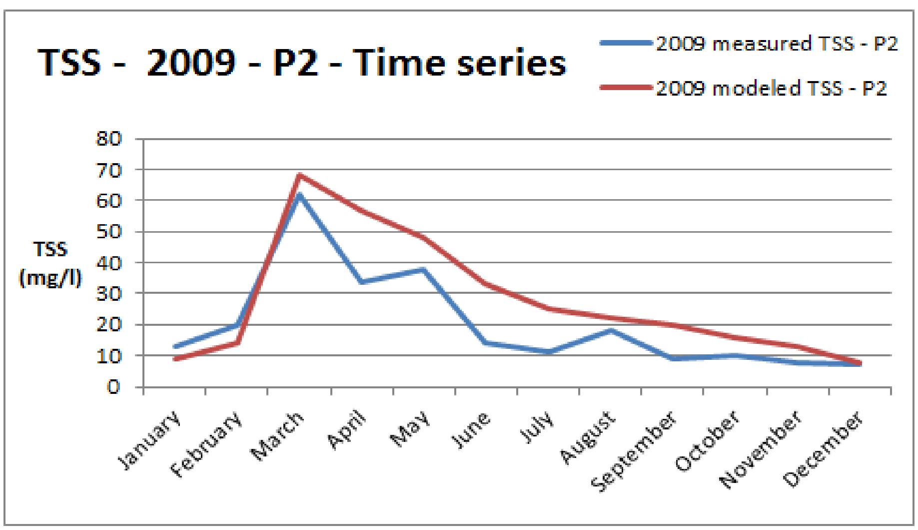


Figure 7.17. Time series for TSS, for both measured and modeled data, in Point 2, 2009

The difference between the modeled data in 2008, 2009 and 2010, is displayed in Figure 7.19. The TSS concentration in March 2009 is 9.5 times higher than the TSS concentration in the same period, in 2008. This was the TSS pollution from bushfires (Figure 7.18).

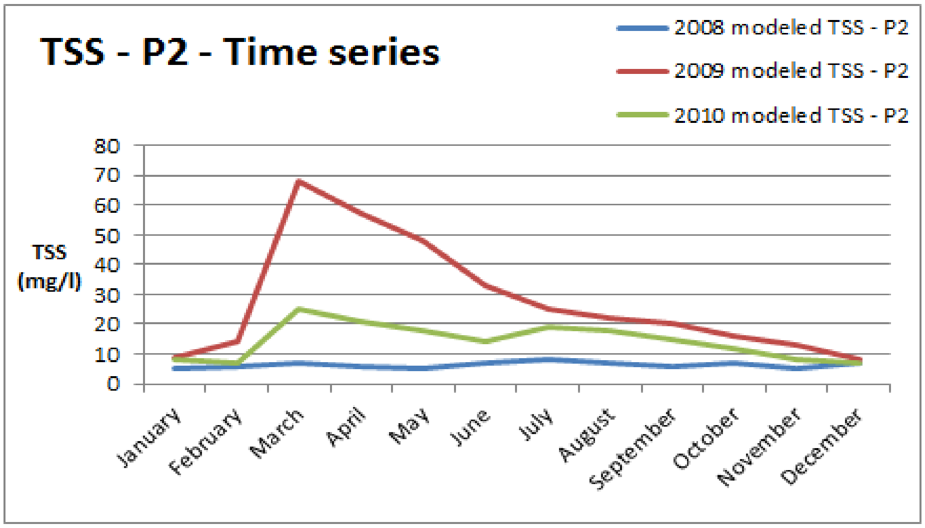


Figure 7.18. Time series for TSS modeled data, for 2008, 2009, 2010, in Point 2

Point 3 is also affected by pollution from bushfires. A large burnt area was washed by the water that flowed towards Point 3. The correlation between the modeled and the measured data is over 0.7, so the model well predicted the TSS levels for Point 3 (Figure 7.19).

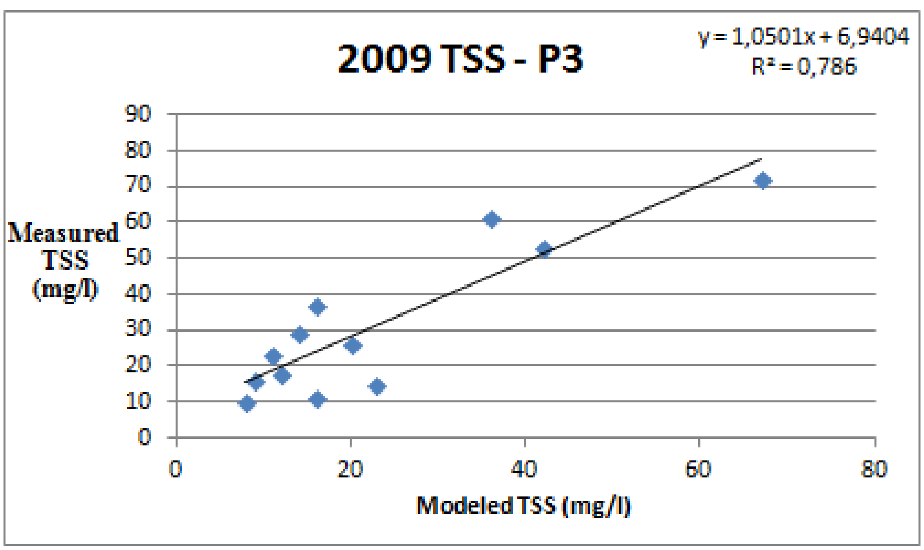


Figure 7.19. Correlation between TSS modeled and measured data for 2009, in Point 3

In Figure 7.20 data shows high levels of TSS after rain, and the TSS values are huge after a bushfire followed by rain. The fact that the measured data did not show a smooth downward trend, as the measured data, is due to some other filter mechanisms and other pollution sources respectively, that are not taken into account in the model. Another possible explanation may be based on the human errors that can be made in water sampling and sample analysis.

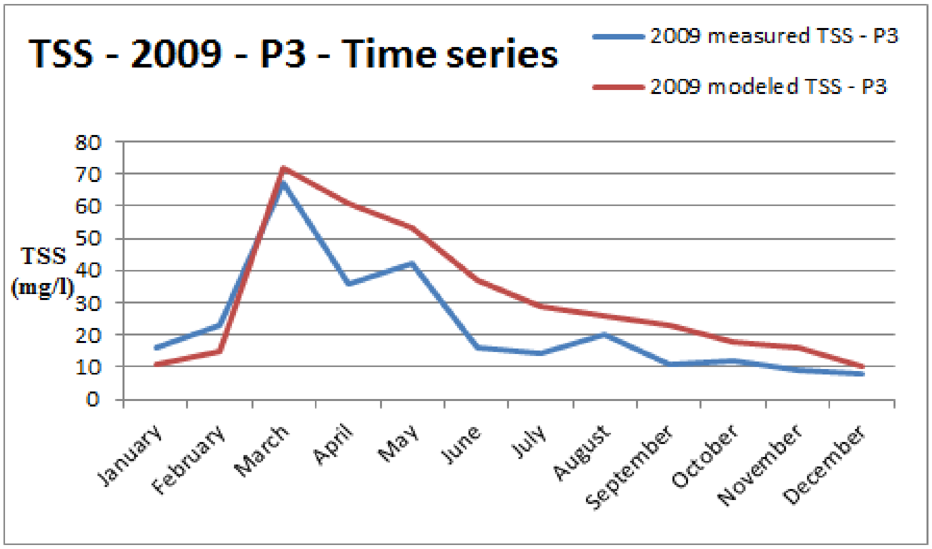


Figure 7.20. Different behaviour between TSS modeled and measured, in P3, in 2009

Another example of good correlation between modeled and measured TSS is represented in Figure 7.21.

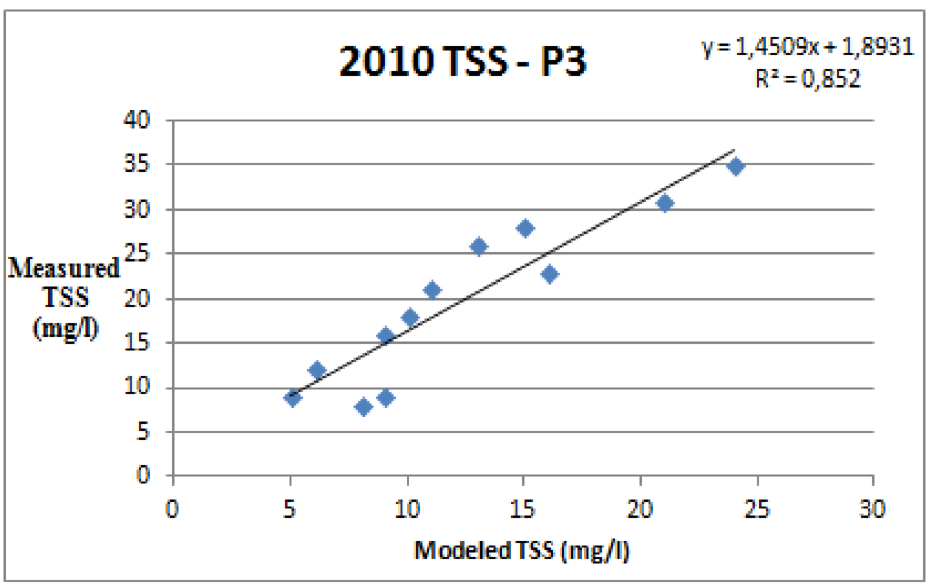


Figure 7.21. Correlation between TSS modeled and measured data in 2010, in Point 3

The time series displayed in Figure 7.22, showed almost the same trend in modeled and measured data.

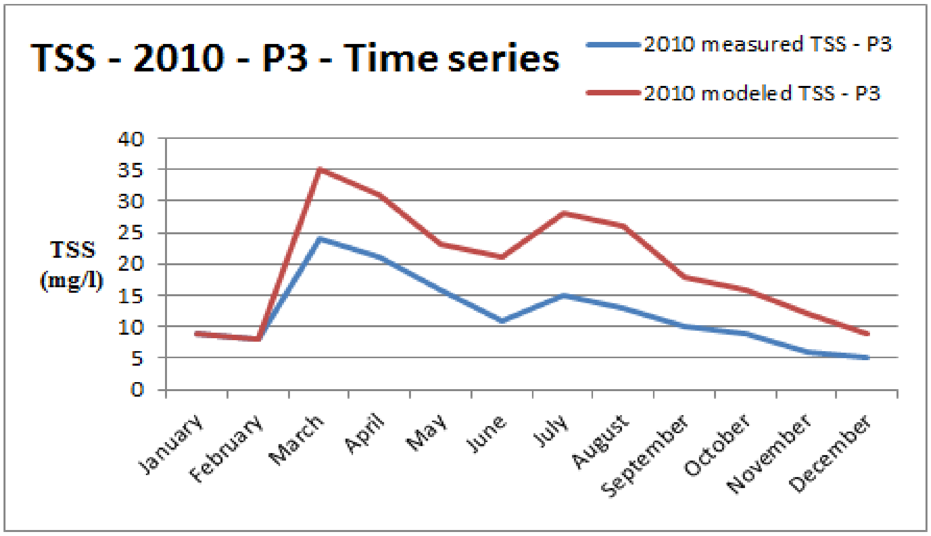


Figure 7.22. The same trend for the TSS modeled and the measured data, 2010

In most of the cases, the modeled data are higher than the measured data, which means that the model overestimated. This is a good thing, because the model predicts a worse situation, and the decisions will be made taken into account the most unfavorable option. The same trend for both modeled and measured data and the overestimating of the model can be seen in figure 7.23.

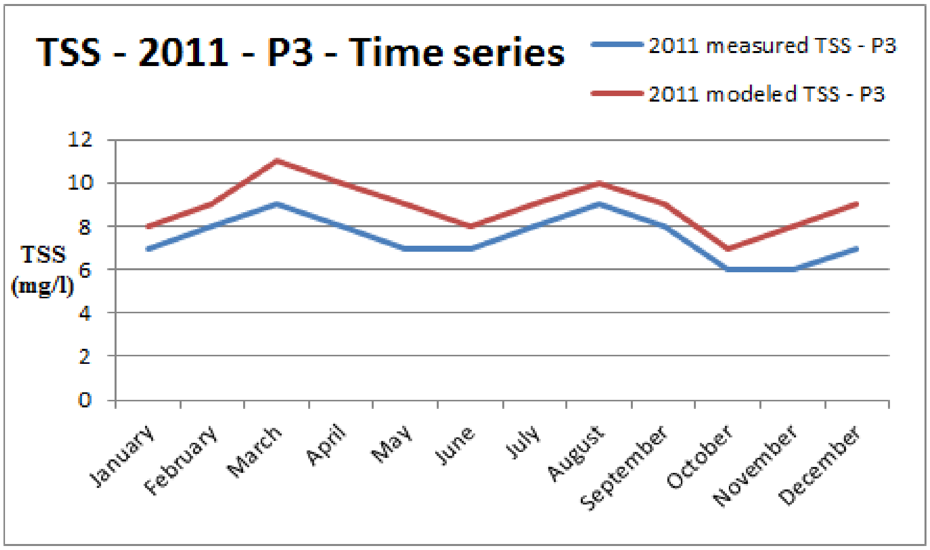


Figure 7.23. The same trend for the TSS modeled and the measured data in P3, 2011

A comparison between years, from 2009 to 2016 for TSS, modeled data are presented in Figure 7.24. In 2009, high levels of TSS are provided by the hydrological model. There is a peak in March 2009, when the bushfires were followed by rain for many days. In 2010, the data returned to the normal trend: high levels of TSS in March and then the values decreased. Another peak is around July-August, when there are also rains. Starting with 2011, the TSS levels became normal, with values under 10 mg/l.

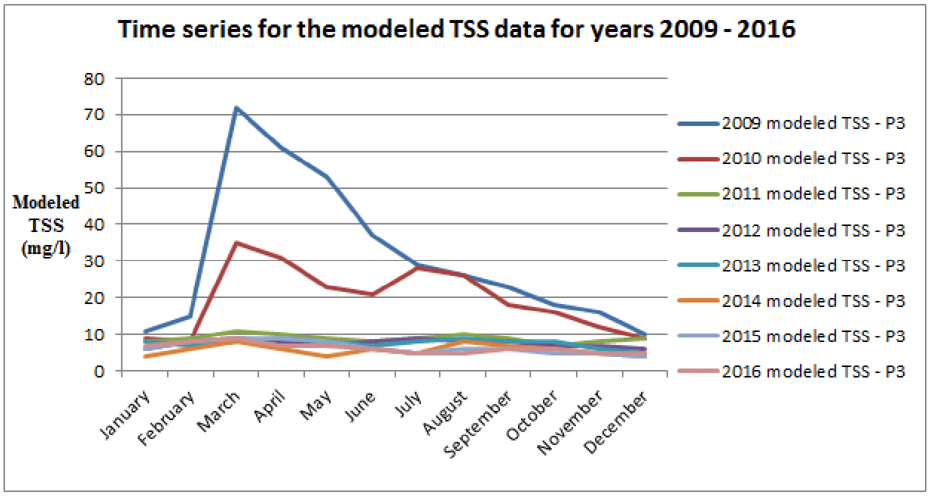


Figure 7.24. Time series for the TSS modeled data for years 2009 to 2016

Point 4 collects the pollution from the four sub-catchments located at higher elevations. The correlation coefficient between the modeled and the measured data in Point 4, in 2008 is 0.8894, as it is displayed in Figure 7.25.

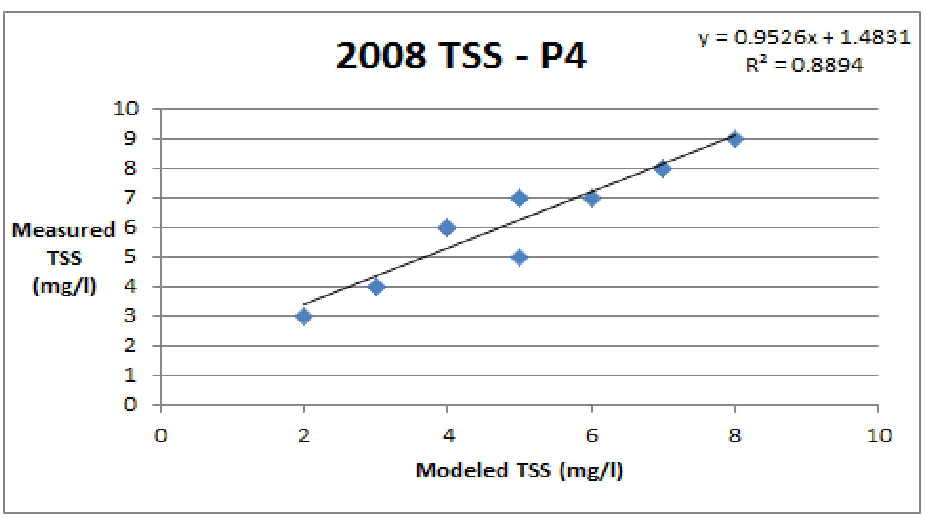


Figure 7.25. Correlation between TSS modeled and measured data in 2008, in Point 4

The trend between the modeled and the measured data in P4, in 2008 is slightly different, the modeled data trend being smoother than the measured data trend (Figure 7.26).

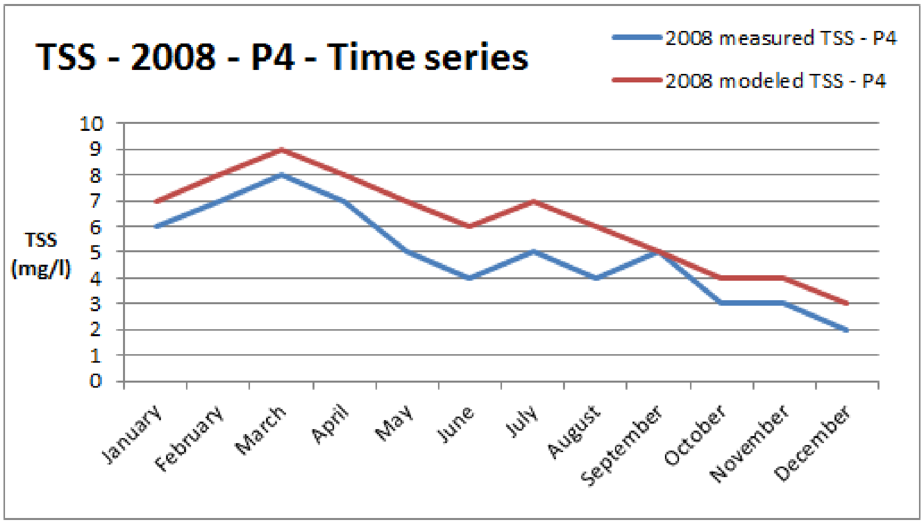


Figure 7.26. Slightly different trend for the TSS modeled and the measured data in 2008, in P4

In 2009, the year when there were bushfires, the correlation between the modeled and the measured data is better, so the model predicted better the TSS values (Figure 7.27).

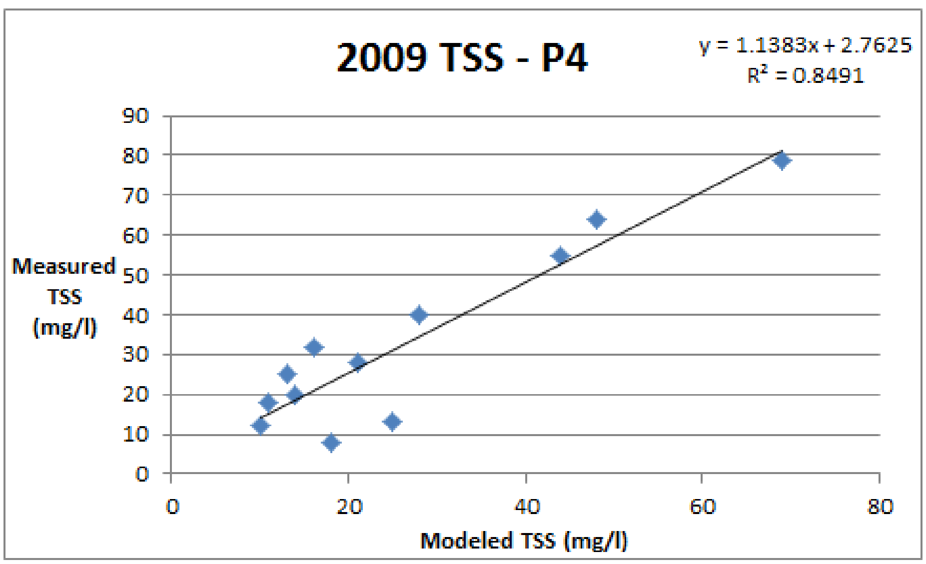


Figure 7.27. Correlation between TSS modeled and measured data in 2009, in Point 4

The model is able to predict the TSS concentrations taken into account the whole catchment. In Figure 7.28, the modeled data from 2009 in Point 3 and Point 4 are displayed. The TSS values in P4 are higher than in P3, P4 being downstream. In P4 were drained the waters that washed the whole burnt area from the catchment. The peak recorded in March 2009 had a value of 72 mg/l in point 3 and 79 mg/l in point 4.

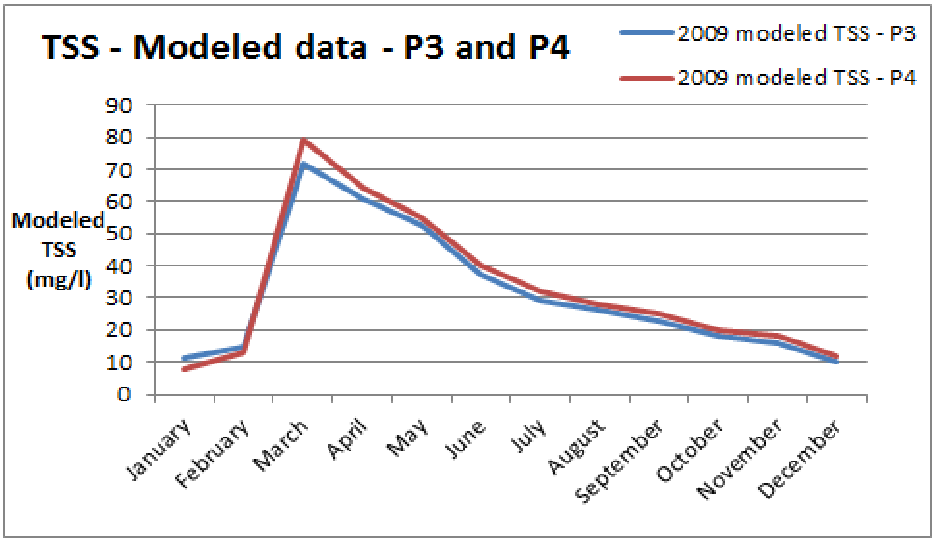


Figure 7.28. Time series for TSS in 2009, in P3 and P4

Good correlations were found in P5, as well. The example of year 2009 is displayed in Figure 7.29, where the correlation coefficient is over 0.8.

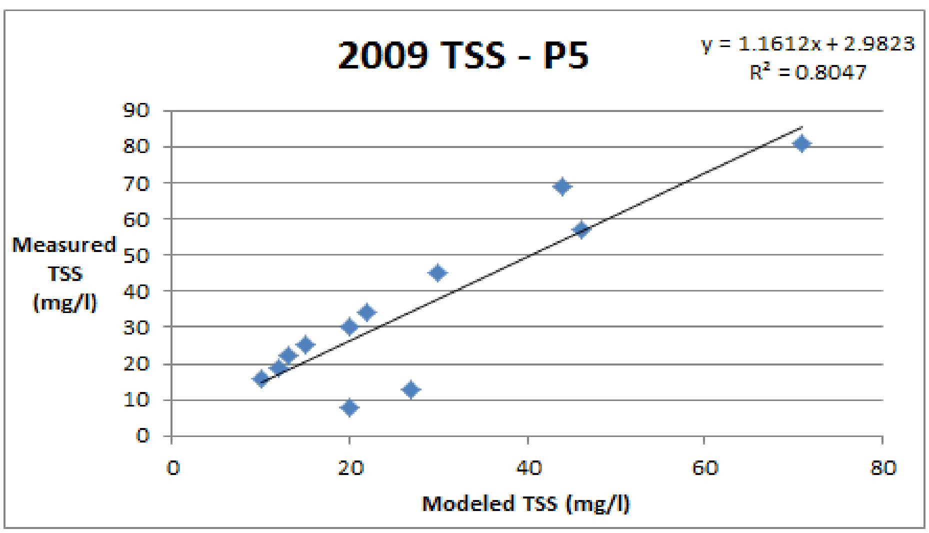


Figure 7.29. Correlation between TSS modeled and measured data in 2009, in Point 5

In P5, there is the same behaviour of modeled and measured data, as it was found in other points: the modeled data trend is smoother than the measured data trend (Figure 7.30).

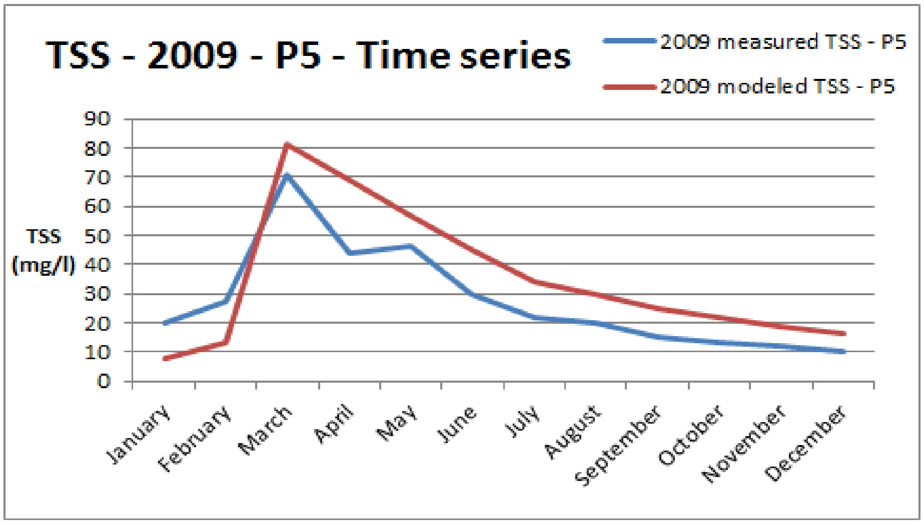


Figure 7.30. Smoother trend of TSS modeled data compared to the measured data in 2009, in P5

Good correlations between the modeled and the measured data were also found in Point 6. In Figure 7.31 there are displayed the data from P6, 2009. The correlation coefficient is 0.8722, which means that the model predicted well enough the TSS levels in P6.

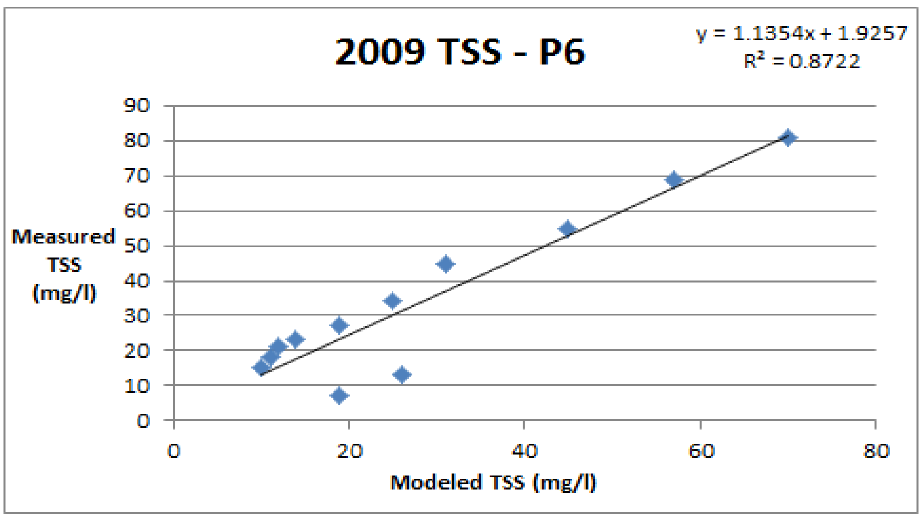


Figure 7.31. Correlation between TSS modeled and measured data in 2009, in Point 6

In the graph below (Figure 7.32), the modeled and measured data for Point 6 are displayed as time series to show the trend. It can be noticed that both trends (modeled and measured data) are similar: after a high peak recorded in March 2009, the values decreased smoothly by the end of year. Also, in January and February, the measured values are slightly higher than the modeled data. The explanation of such a behaviour would be the fact that the model took into account the pollution that appeared after a bushfire followed by a rain. When the bushfires start to burn the area, the wind could have transported small quantities of pollutants, which were deposited around, a part of them on the river water. This pollution could have been expressed in the measured values recorded in January and February that are double compared to the modeled data in the same period.

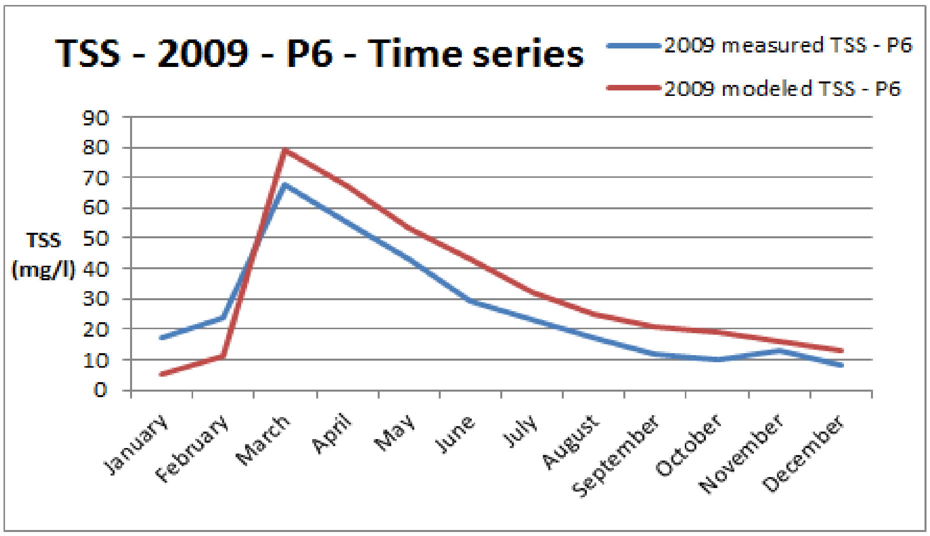


Figure 7.32. Time series of TSS modeled data and measured data in 2009, in P6

In Figure 7.33, the measured TSS values in 2009, for all 6 monitoring points are displayed. The pollution from the bushfires did not affect P1. The highest TSS value, in 2009, was recorded in P5, although P6 is more downstream than P5, because the waters that flowed from areas without bushfires diluted the pollution from Latrobe River.

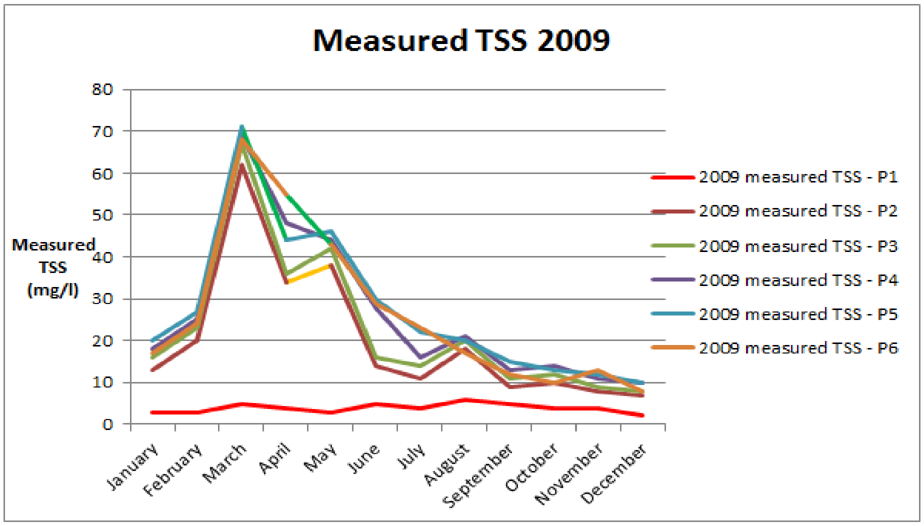


Figure 7.33. Time series of TSS measured data in 2009, for points 1 to 6 in Latrobe catchment

The time series of the modeled data predicted for 2009, for all 6 points showed the same behaviour as the measured data (Figure 7.34). The highest value of TSS was obtained in March, in P5, so the model took into account the process of dilution that took place in the river.

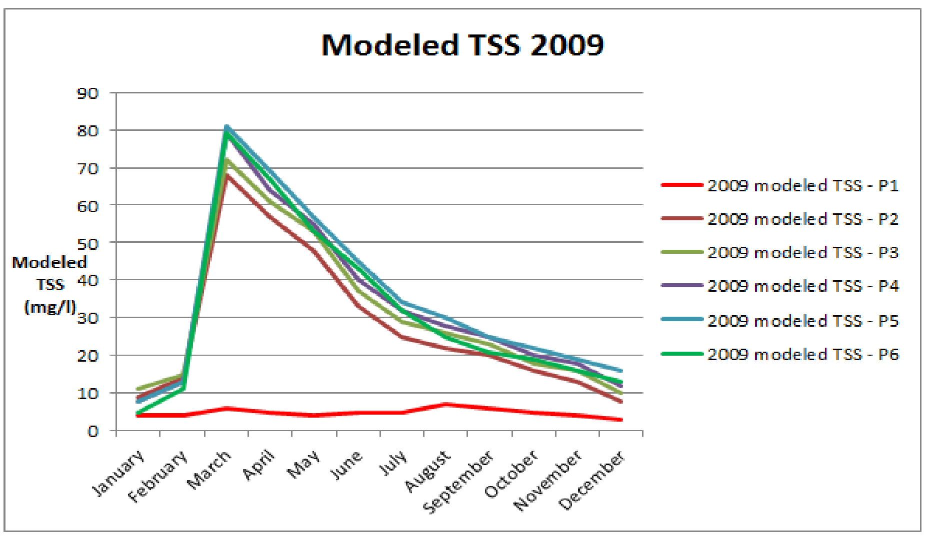


Figure 7.34. Time series of TSS modeled data in 2009, for points 1 to 6 in Latrobe catchment

In the graph below (Figure 7.35) the TSS measured levels in P3, for all years between 2008 and 2016 are plotted. The highest values of TSS were recorded in 2009, when the bushfires were in the Latrobe catchment. The next year, 2010, the TSS values are still high, but starting from 2011, the TSS levels return to normal. So the TSS pollution after bushfires in Latrobe catchment persisted one more year after 2009.

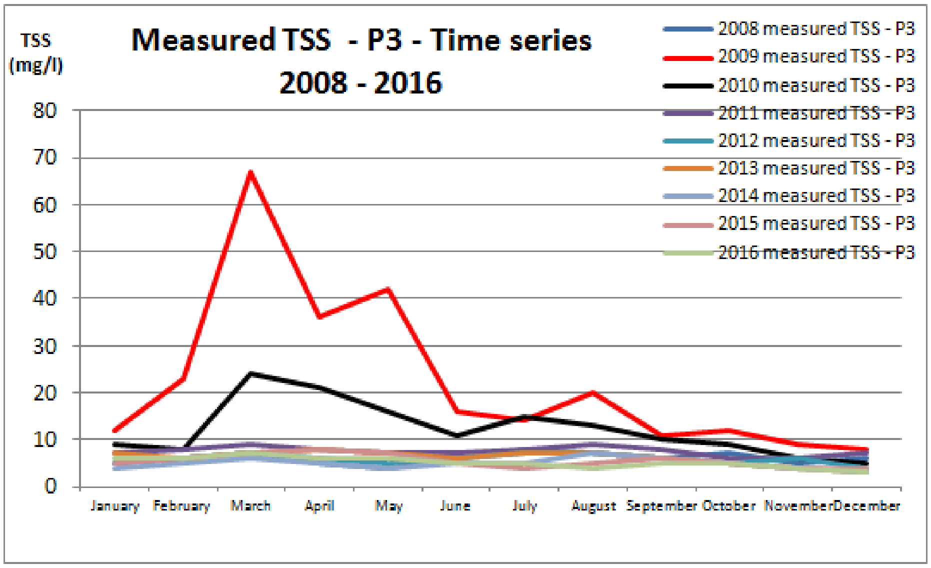


Figure 7.35. Time series of TSS measured data in P3, 2008-2016

The modeled TSS values presented the same characteristic, so the model well predicted the TSS levels in the catchment (Figure 7.36)

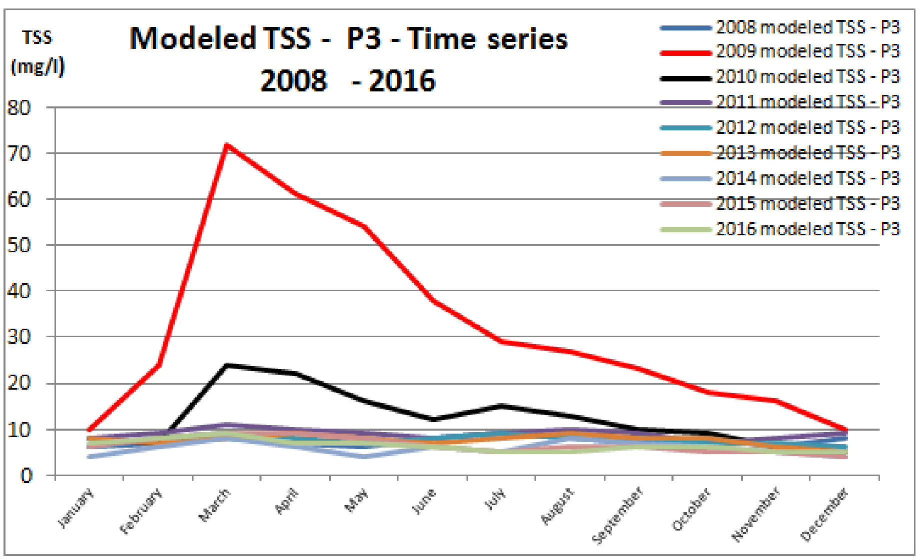


Figure 7.36. Time series of TSS modeled data in P3, 2008-2016

7.4.3. Validation and evaluation of the model for TN

The analysis of the TN levels in the Latrobe catchment showed that they were high after rain, and they reached large concentrations after a bushfire followed by rain.
The correlation coefficients between the modeled and the measured TN had values higher than 0.8, which means a good correlation between them. The trend for the modeled and the measured data is almost the same, with small differences. An example for 2008, of correlation between the modeled and measured TN, for the monitoring Point 1, was presented in Figure 7.37.

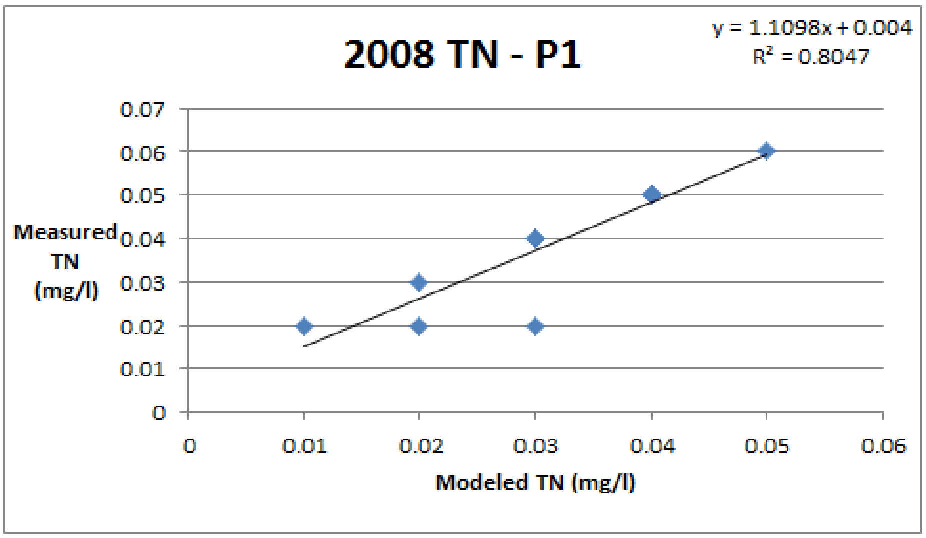


Figure 7.37. Correlation between the TN modeled and measured data in P1, 2008

For 2009, the correlation between the modeled and the measured data in P1 is even better (Figure 7.38).

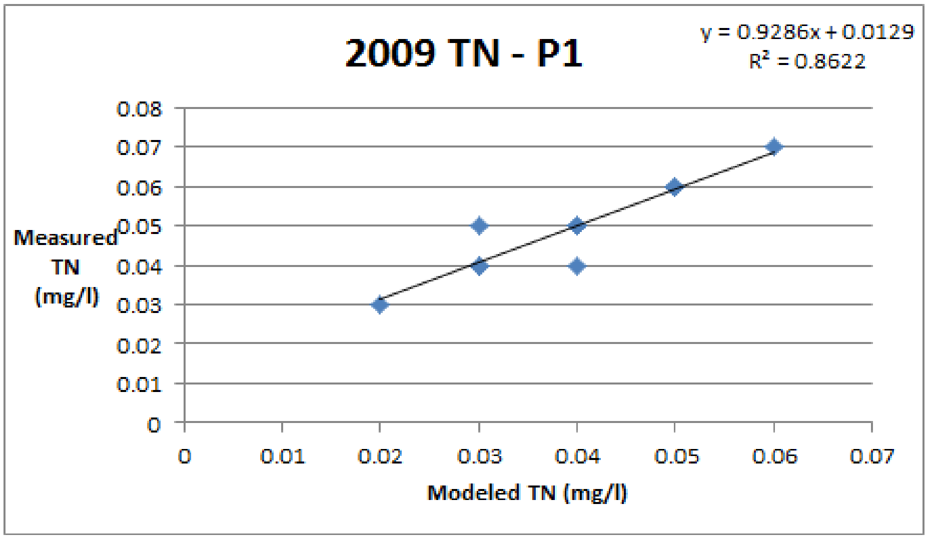


Figure 7.38. Correlation between the TN modeled and measured data in P1, 2009

The time series for both modeled and measured data showed almost the same trend, which means that the model is able to predict the general behaviour of the data (Figure 7.39).

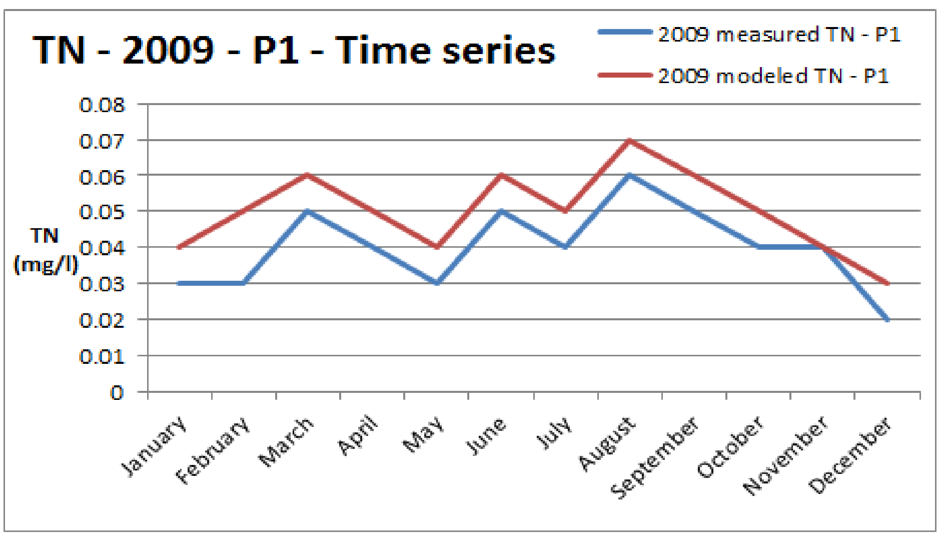


Figure 7.39. Time series of TN modeled and measured data in P1, 2009

Comparing the TN modeled data for 2008, 2009 and 2010 (Figure 7.40), the values were between 0.02 and 0.07 mg/l, so the bushfires in 2009 did not affect the TN values at Point 1. The burnt areas are situated downward from Point 1.

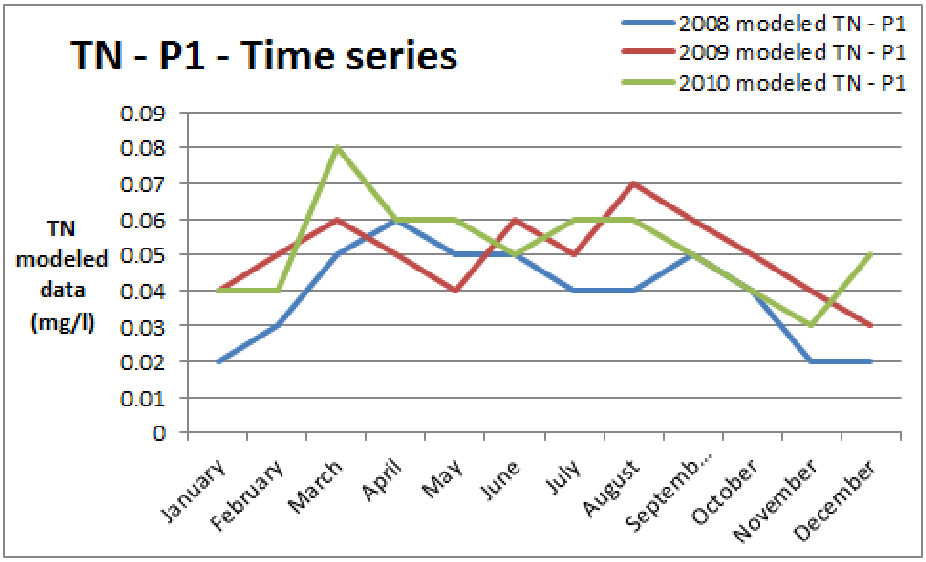


Figure 7.40. Time series of TN modeled data in P1, 2008, 2009, 2010

The model was able to predict the TN concentrations in Point 2, as well. In Figure 7.41, the correlation between the TN modeled and measured is displayed.

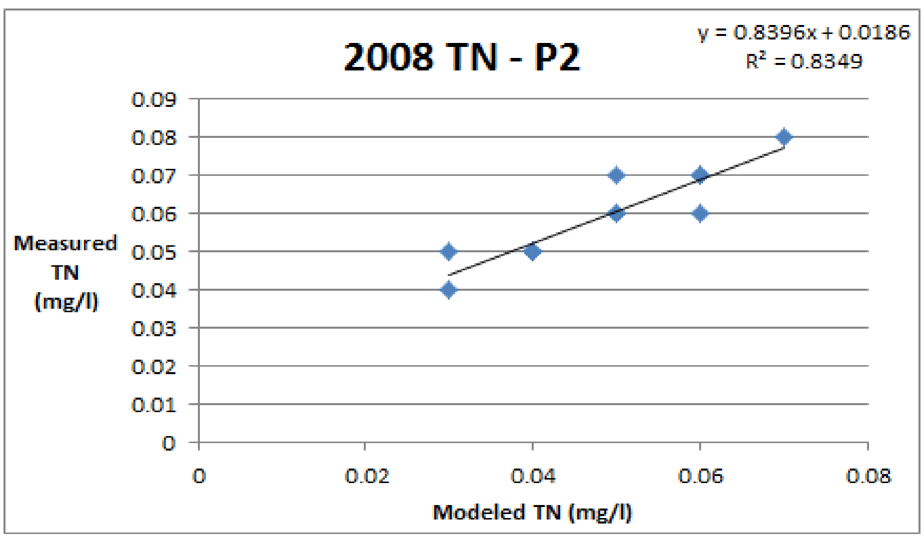


Figure 7.41. Correlation between the TN modeled and measured data in P2, 2008

For 2009, the correlation between the TN modeled and the measured data is very good, much better than for the other years for when *eWater* was run. This was displayed in Figure 7.42.

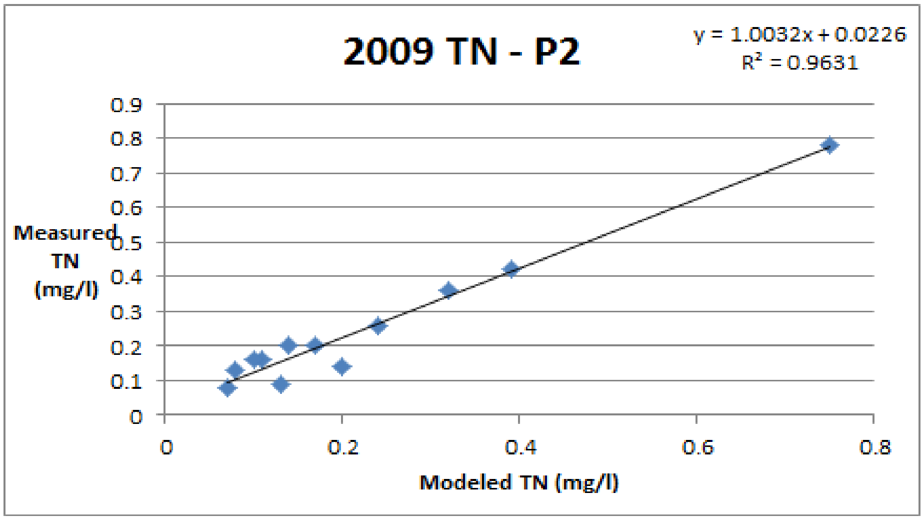


Figure 7.42. Correlation between the TN modeled and measured data in P2, 2009

In figure below (Figure 7.43) the time series for TN modeled and measured data in P2 for 2009 are plotted. The trend for both sets of data is similar, but the modeled values are higher than the measured data, so the model overestimated.

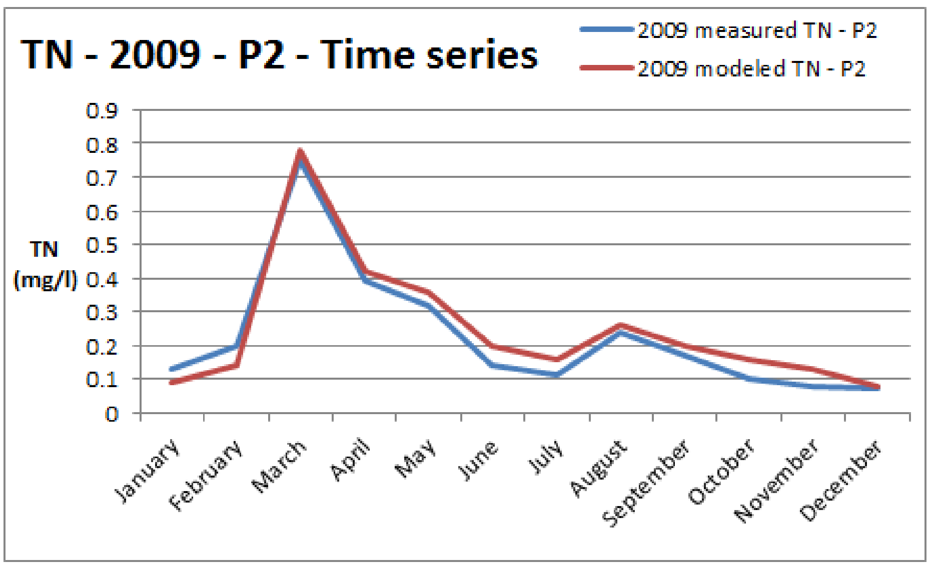


Figure 7.43. Time series of TN modeled and measured data in P2, 2009

The comparison between the TN modeled data for 2008, 2009 and 2010 is plotted in Figure 7.44. The graph shows low values in 2008, very high values in 2009, and medium values of TN in 2010. The impact of the pollution from bushfires is very well expressed in the modeled data. The model is able to predict this pollution in Point 2, which is in the downstream to a part of the burnt areas.

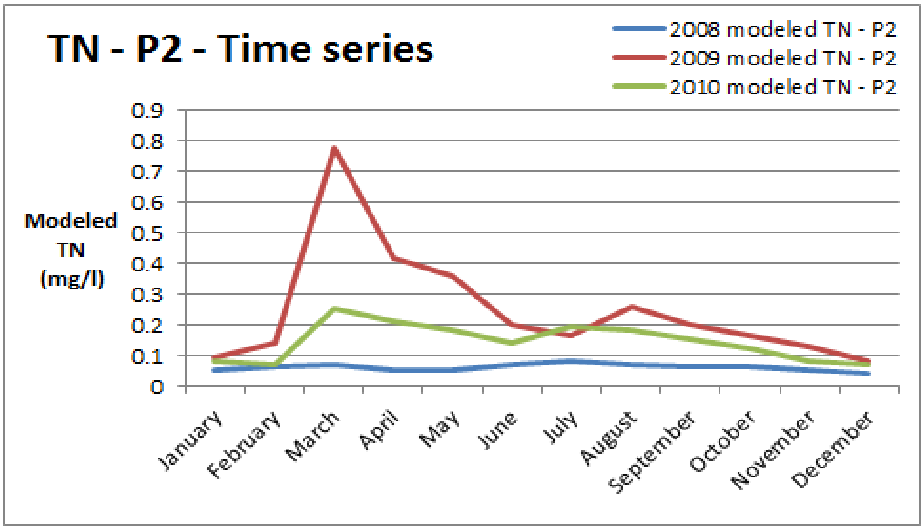


Figure 7.44. Time series of TN modeled data in P2, for 2008, 2009, 2010

In Point 3, the correlation between the modeled and the measured data is displayed. The correlation coefficient is 0.8294, so the model predicted the TN in this point closely (Figure 7.45).

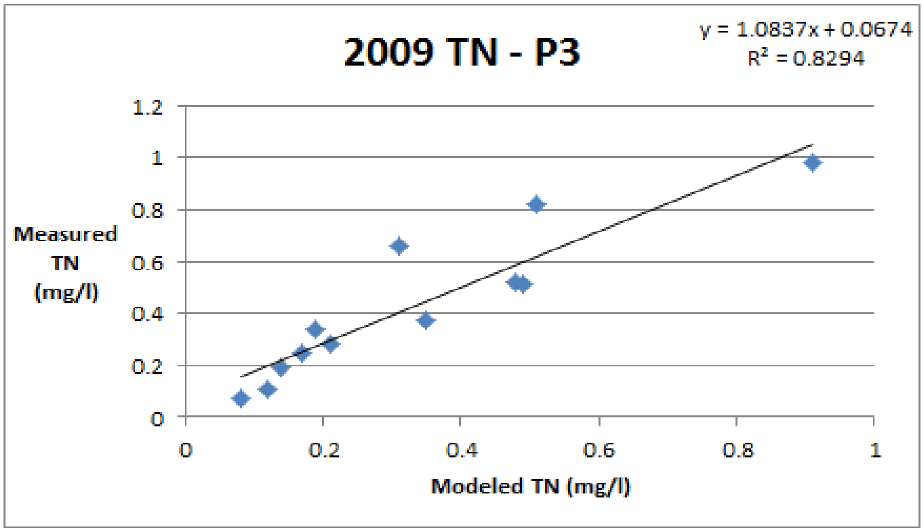


Figure 7.45. Correlation between the TN modeled and measured data in P3, 2009

The behaviour of the modeled and measured data is similar, especially since March 2009, when the bushfires pollution was transported into streams. The model slightly overestimated (Figure 7.46).

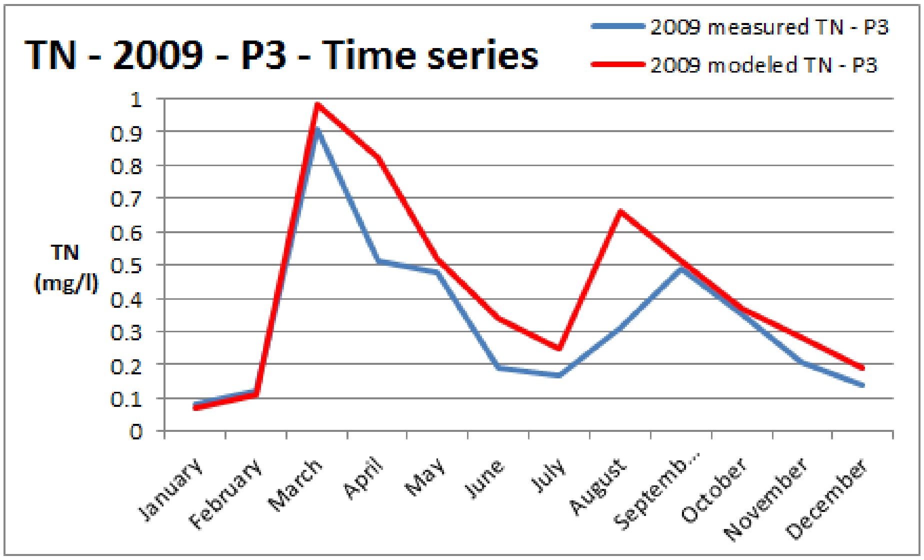


Figure 7.46. Time series of TN modeled and measured data in P3, for 2009

The TN values measured in 2008 were generally low then the highest values were recorded in 2009, the year when bushfires took place in the upward area to Point 3. In 2010, the values decreased, in 2011, the values are lower compared to 2010, but were still higher comparing to 2008 and 2010 until 2016. It was only in 2012, when the TN values took the regular values, so the impact of bushfires dissapeared after 3 years (Figure 7.47).

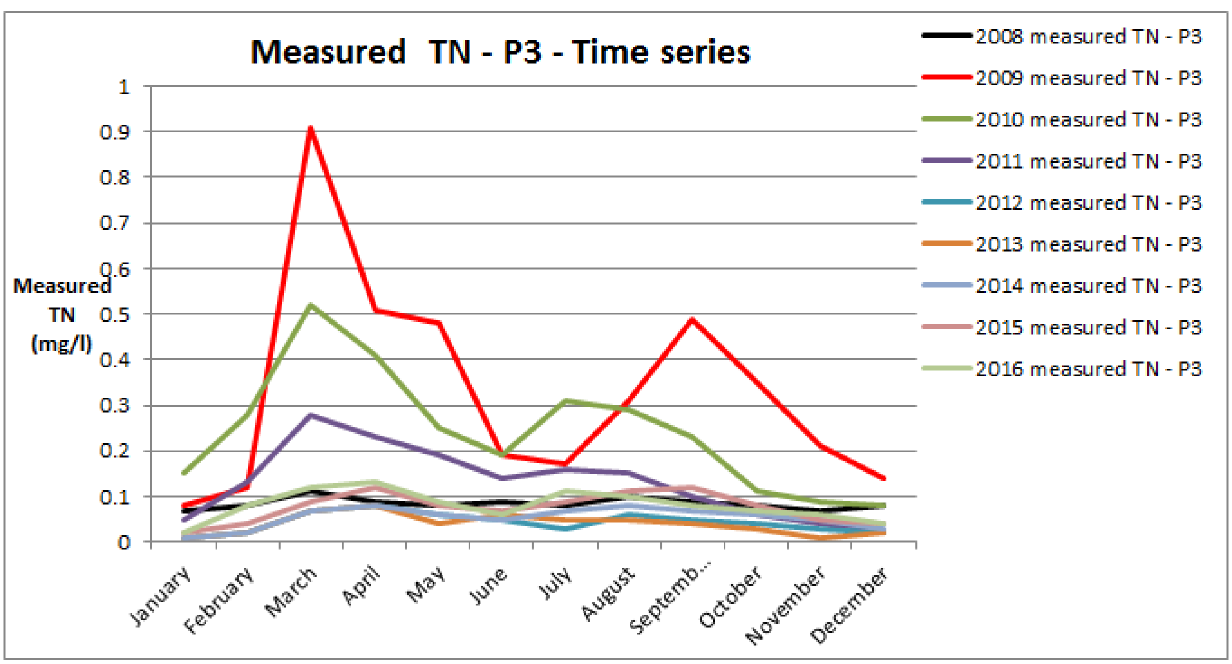


Figure 7.47. Time series of TN measured data in P3, for 2008-2016

eWater predicted the TN values in P3, for years 2008-2016 closely, and the comparison between all years for the modeled data was plotted in Figure 7.48. The model well captured the impact of bushfires in the next 3 years after they happened, the modeled data having similar behaviour as the measured data.

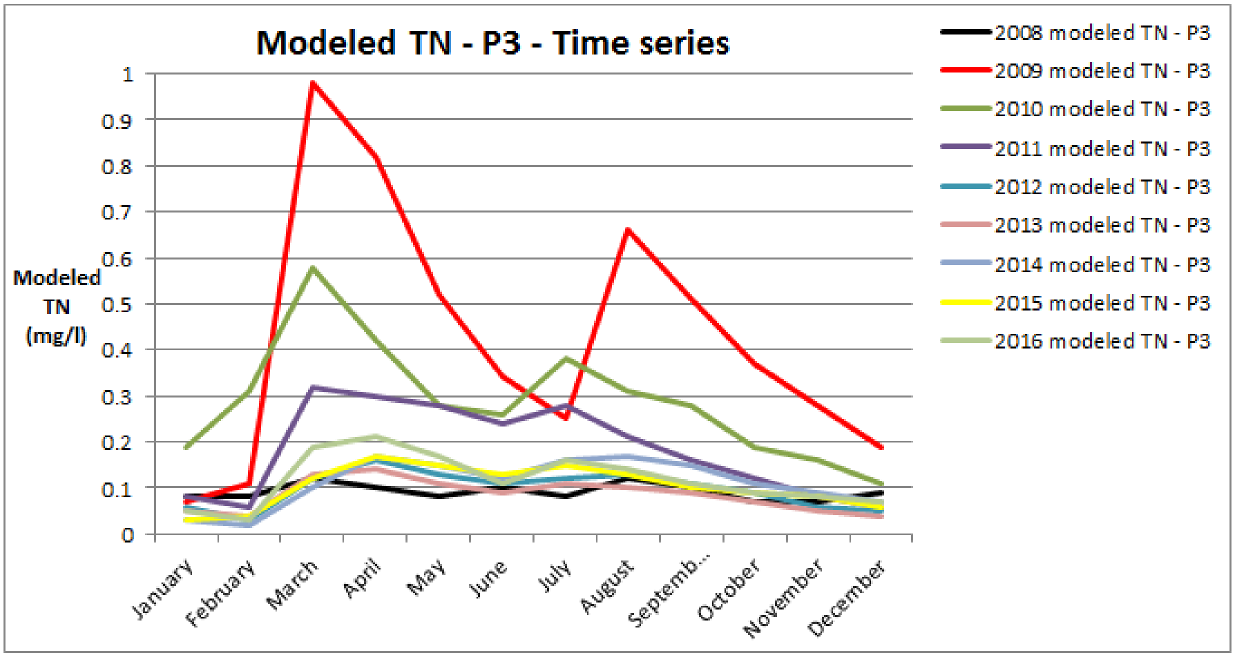


Figure 7.48. Time series of TN modeled data in P3, for 2008-2016

The correlation between the modeled and measured TN in Point 4 is plotted above (Figure 7.49). The correlation coefficient is 0.8888, so the model modeled the TN in this case with accuracy.

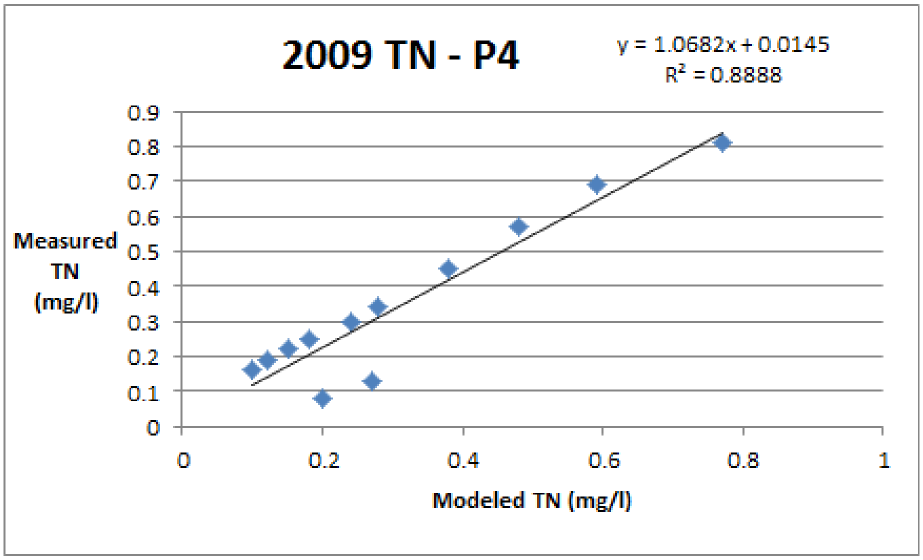


Figure 7.49. Correlation between the TN modeled and measured data in P4, 2009

eWater designed the behaviour of TN very closed to the measured data. Still the modeled data are higher, so the model overestimated (Figure 7.50).

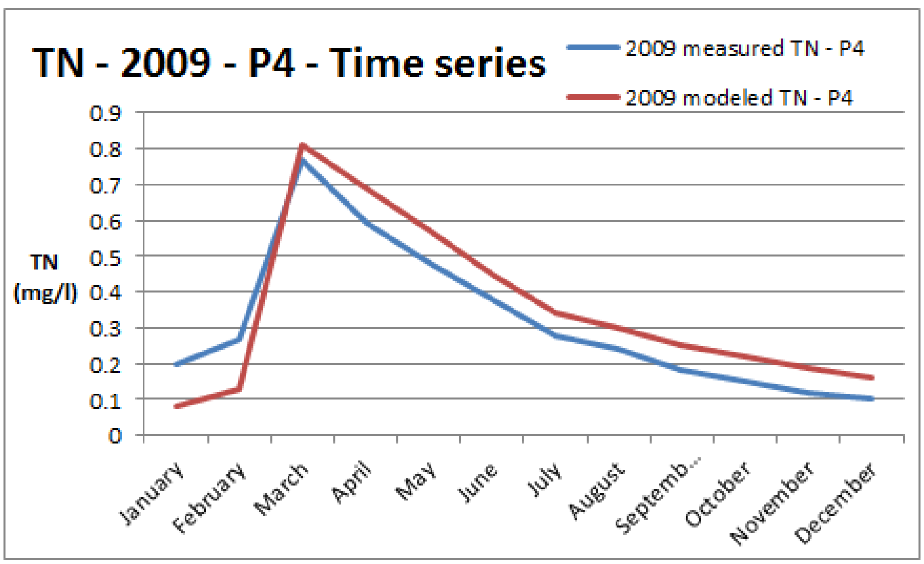


Figure 7.50. Time series of TN modeled and measured data in P4, for 2009

In P5 the model predicted very well the TN values. The correlation between the modeled and the measured TN is displayed in Figure 7.51. The correlation coefficient is greater than 0.9, which means that it is a very good fit between the data.

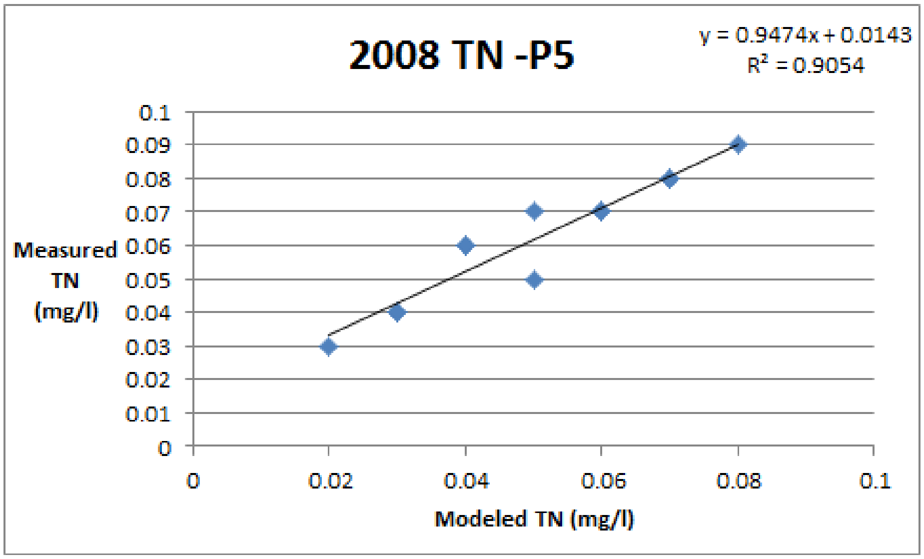


Figure 7.51. Correlation between the TN modeled and measured data in P5, 2008

The variability of the measured data is higher than the modeled data, which are smoother. Overall, the modeled data followed the measured data trend, but the modeled data are still overestimated (Figure 7.52). The difference is less than 5% of the value, so it is relatively small.

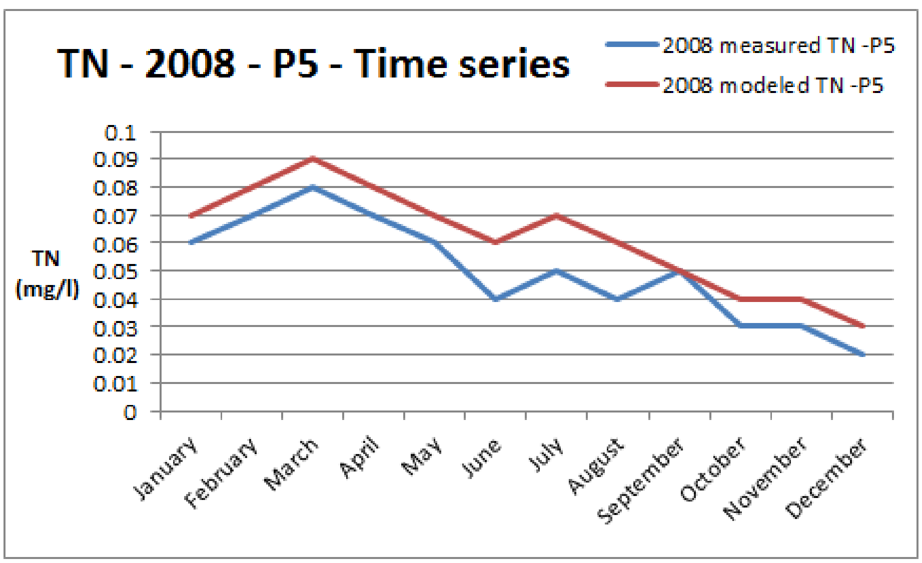


Figure 7.52. Time series of TN modeled and measured data in P5, for 2008

The correlations are better in 2009, compared to 2008, as it can be seen in Figure 4.53.

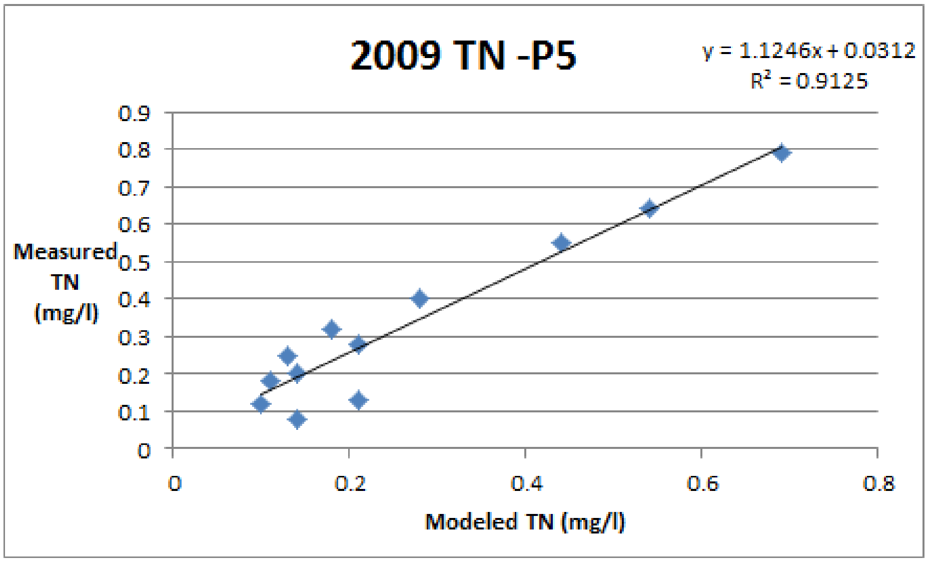


Figure 7.53. Correlation between the TN modeled and measured data in P5, 2009

The trend of both modeled and measured data is displayed in Figure 7.54. The graph displayed the same behaviour of data as it was noticed for the first 4 points.

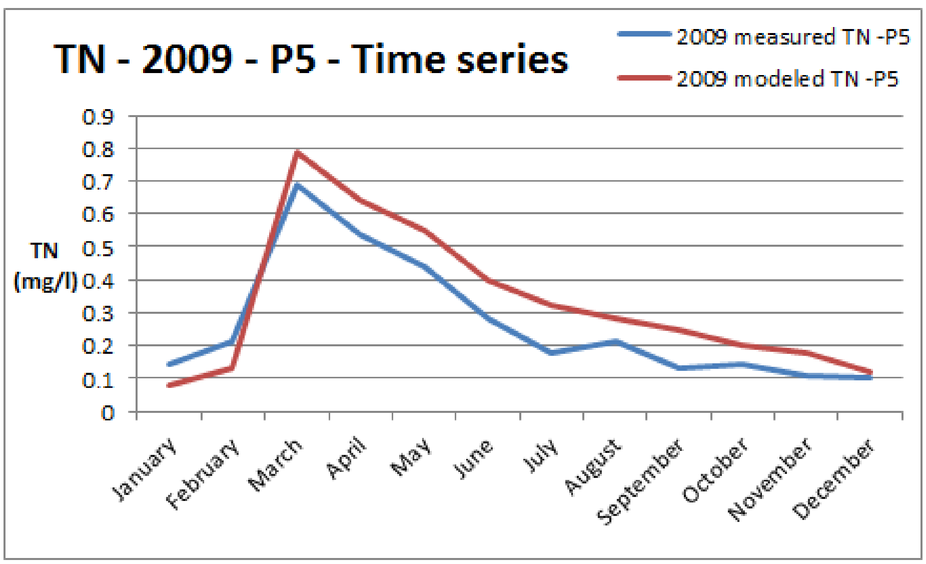


Figure 7.54. Time series of TN modeled and measured data in P5, for 2009

In the graph below (Figure 7.55), the correlation between the modeled and the measured TN in P6 for 2009 was displayed. The model very well predicted the TN values, taking into account the impact of bushfires in the catchment.

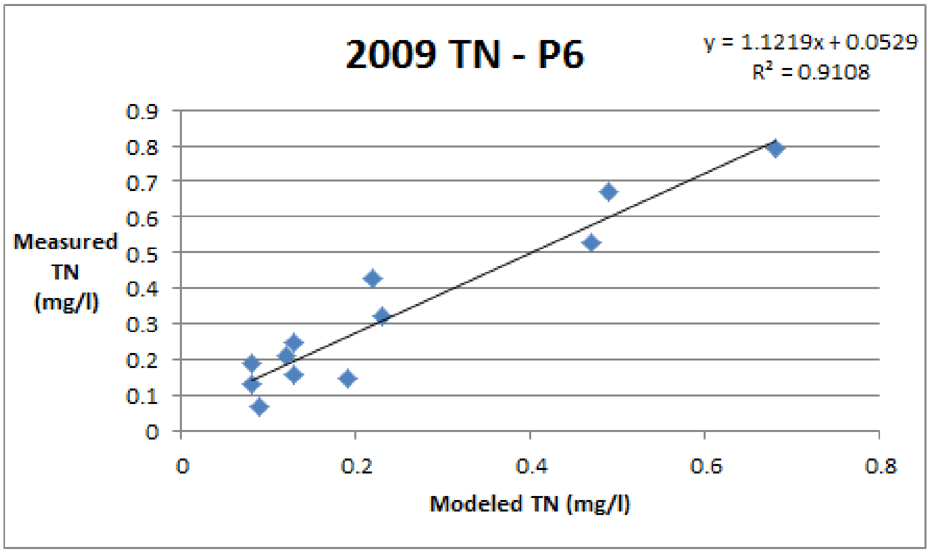


Figure 7.55. Correlation between the TN modeled and measured data in P6, 2009

The modeled data decreased in a smoother way compared to the measured data (Figure 7. 56): might be some other factors that influence the TN pollution in the river.

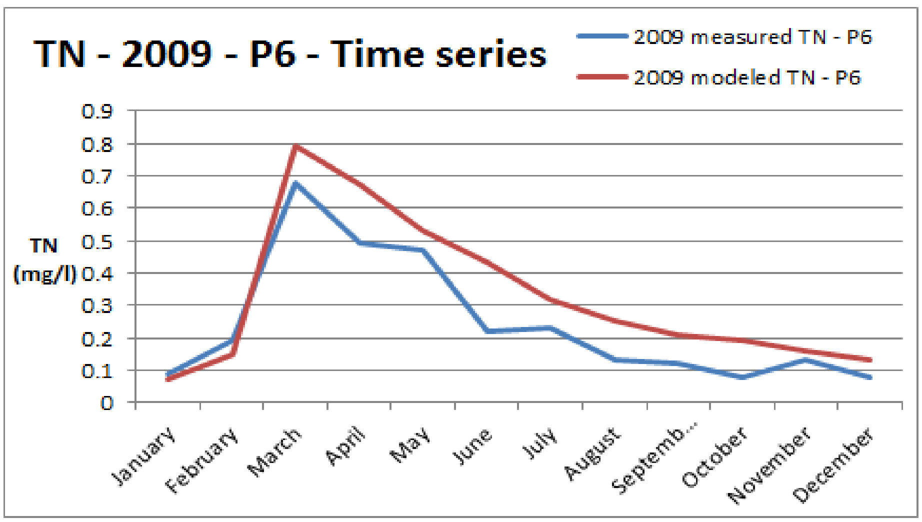


Figure 7.56. Time series of TN modeled and measured data in P6, for 2009

In the graph below (Figure 7.57), the comparison between the measured data recorded in P1, P2 and P3 is displayed. The highest TN values were recorded in P3, because a larger burnt area is situated upward this point, and the TN quantities from this area were transported into the stream before point P3.

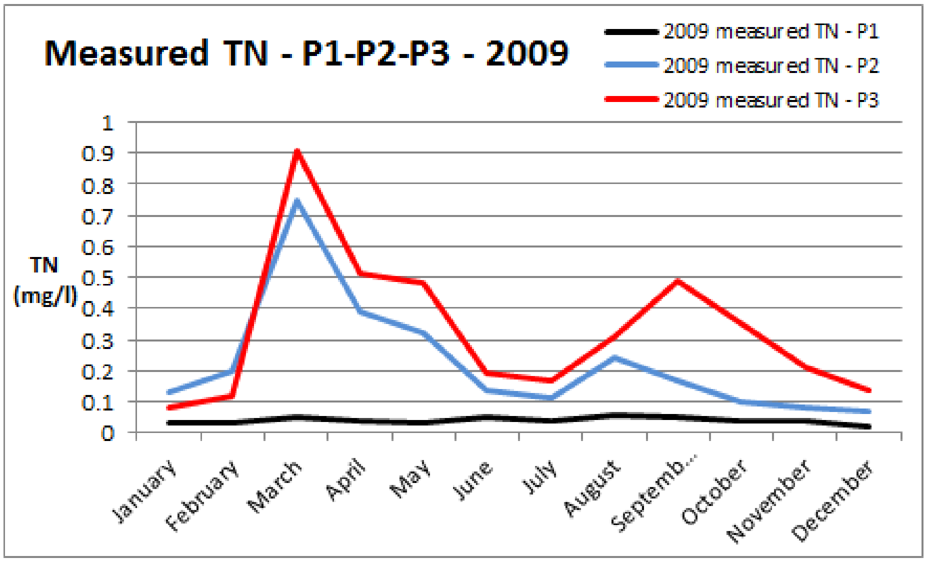


Figure 7.57. Time series of TN measured data in P1, P2, P3, for 2009

The modeled data in points 1, 2 and 3 presented the same behaviour. The highest values were also predicted in P3 (Figure 7.58).

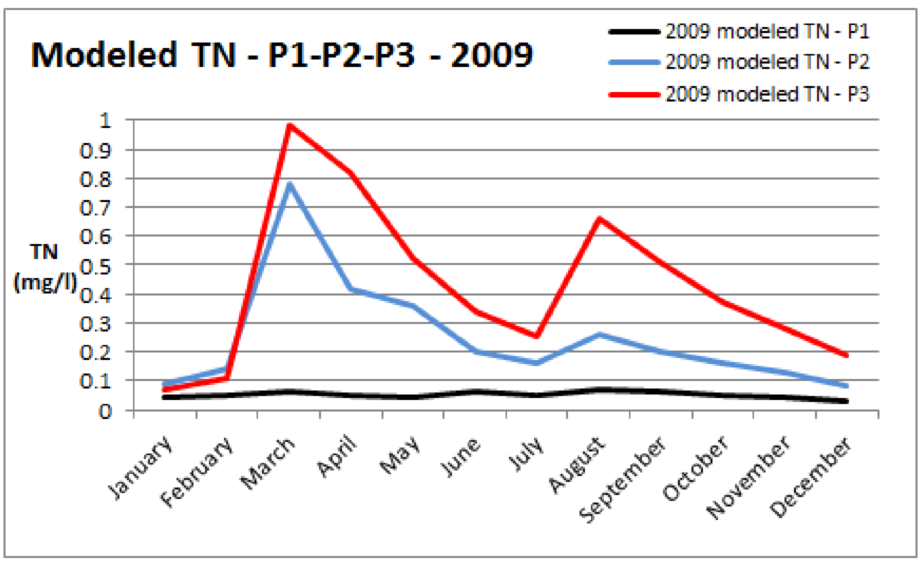


Figure 7.58. Time series of TN modeled data in P1, P2, P3, for 2009

Compared the measured TN values in P3, P4, P5 and P6 for 2009, the highest values were recorded for P3, as well. This means that the pollution that reached P3 was then diluted, so the TN values in P4, P5 and P6 decreased slowly (Figure 7.59).

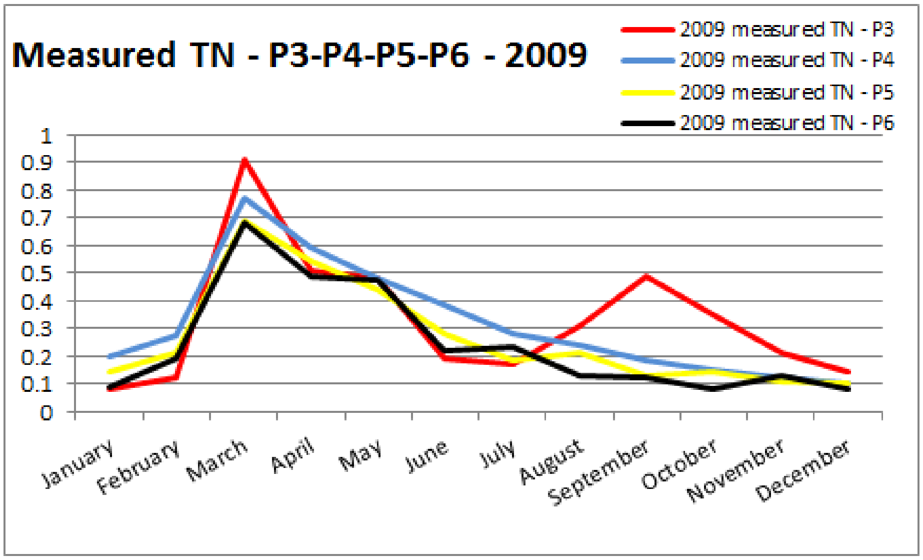


Figure 7.59. Time series of TN measured data in P3, P4, P5, P6 for 2009

In the graph below (Figure 7.60), the modeled TN values in Points 3,4,5 and 6 were displayed. The predicted values were higher in P3, and then gradually decreased from P4 to P6.

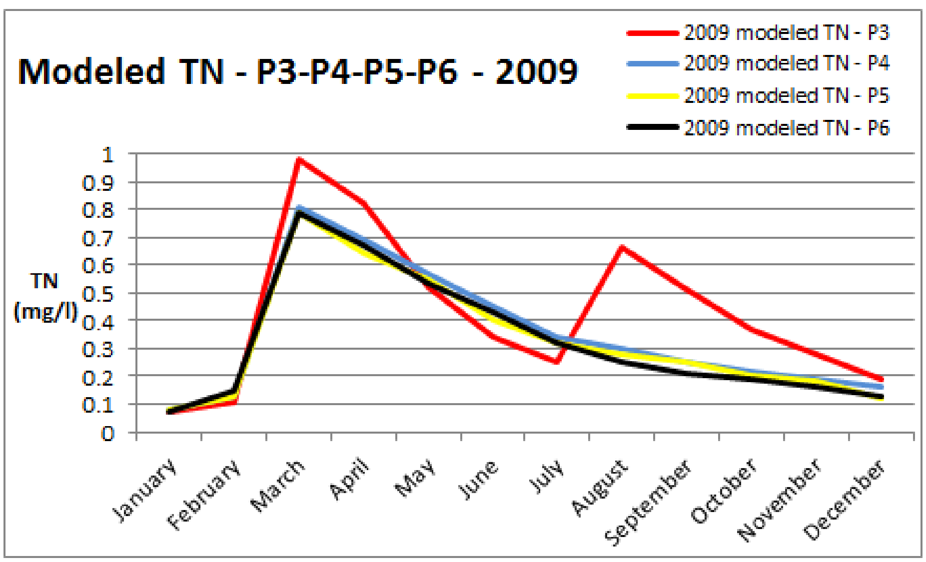


Figure 7.60. Time series of TN modeled data in P3, P4, P5, P6 for 2009

The graph below (Figure 7.61) showed that the pollution from bushfires, produced in 2009 was vanished after 2013. So, this TN pollution persisted for about 4 years.

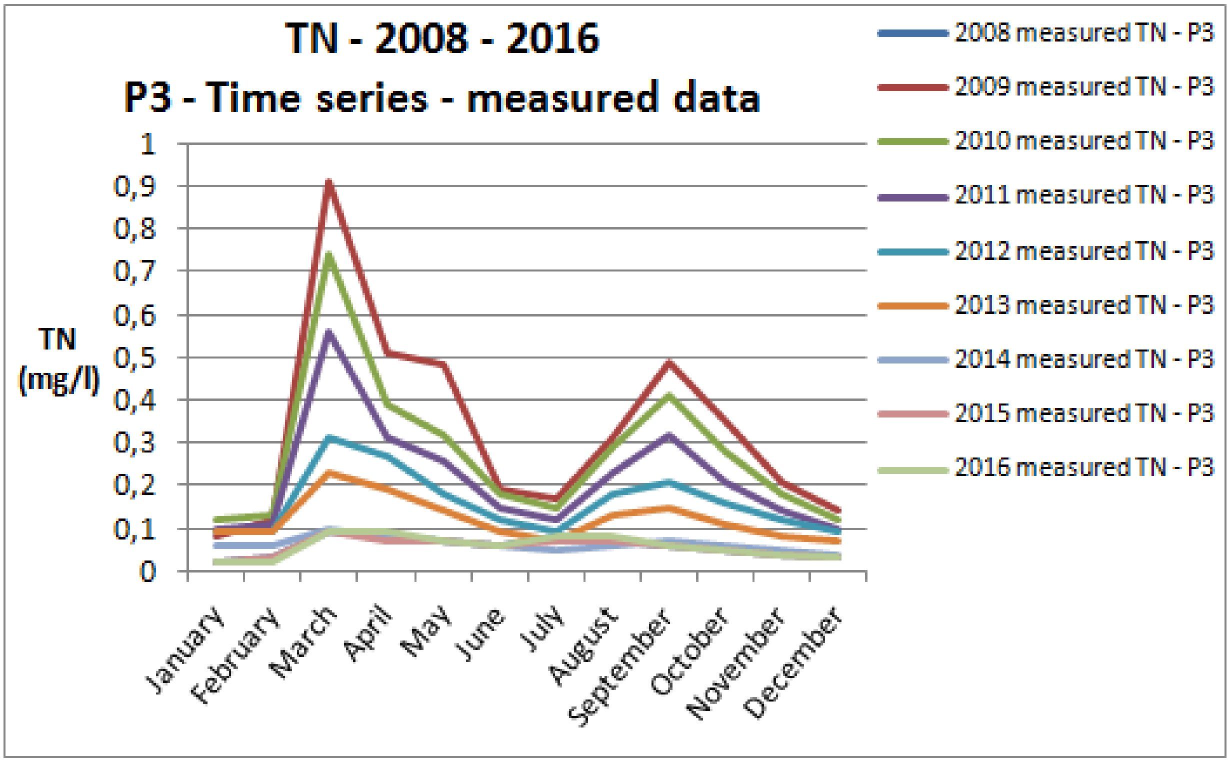


Figure 7.61. Time series of TN measured data in P3

The model closely predicted the TN pollution and its remaining time in the catchment to the measured values. Figure 7.62 displayed the modeled data in P3 for all years between 2008 and 2016. In 2014 the TN levels came close to normal, as the measured data showed in the above graph.

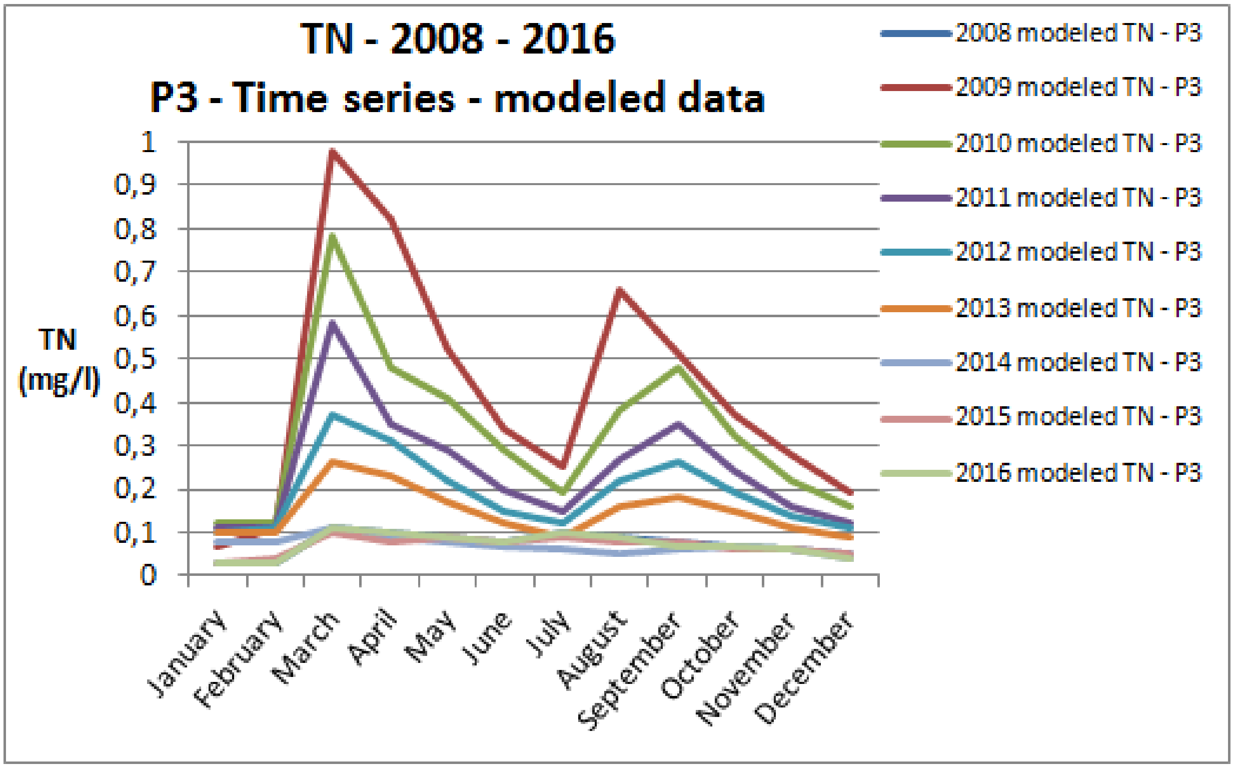


Figure 7.62. Time series of TN modeled data in P3

7.4.4. Validation and evaluation of the model for TP

High values of TN after rain were recorded and the rain after bushfires transported large quantities of TP in the streams, increasing the pollution levels in the water.

The model predicted the TP levels in all six points in the Latrobe catchment closely as discussed in this section..

In Point 1, the correlation for 2008 is displayed in Figure 7.63.

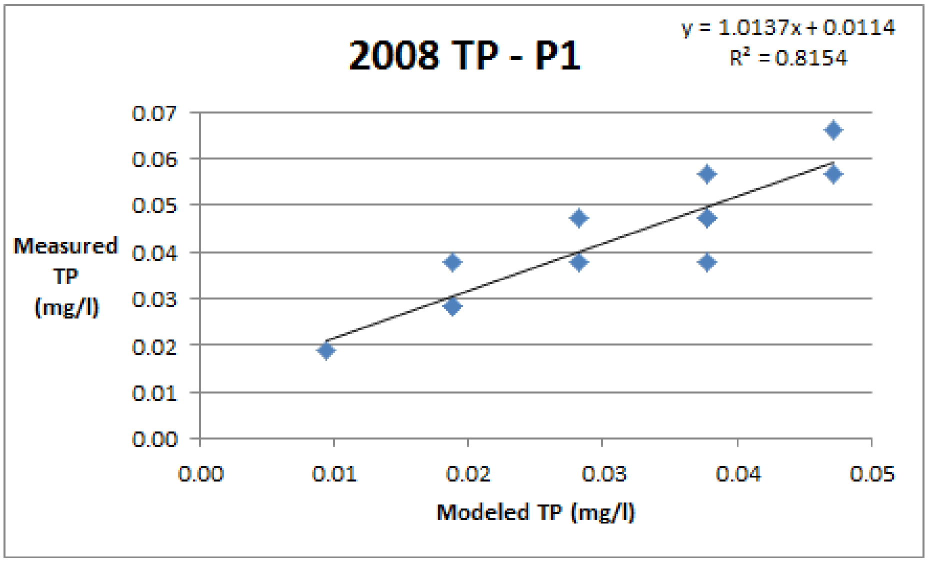


Figure 7.63. The correlation between the TP modeled and measured data, 2008, in P1

For 2009, the data presented a similar situation. The correlation coefficient is higher than in 2008, as it can be noticed from the graph below (Figure 7.64).

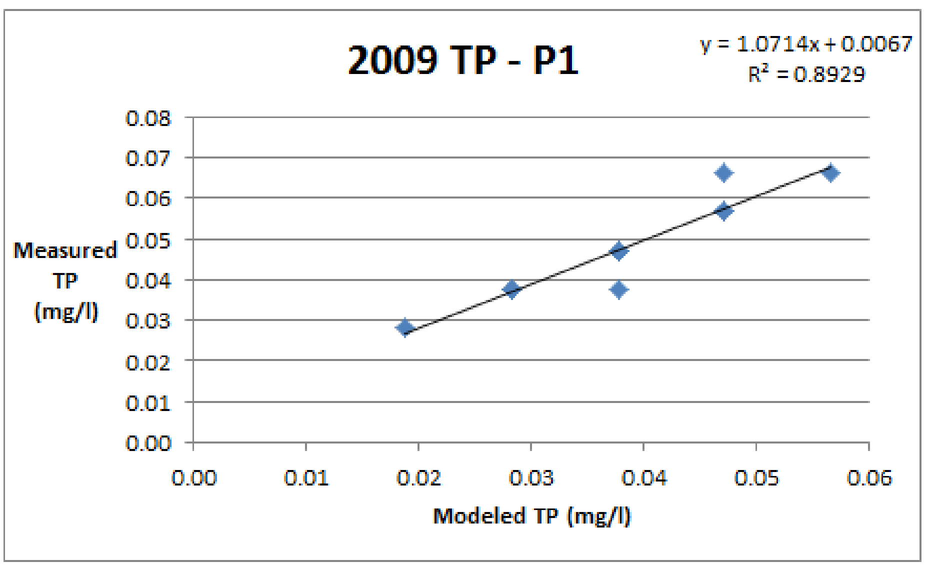


Figure 7.64. The correlation between the TP modeled and measured data, 2009, in P1

While the modeled values followed the same trend as the measured values, the most of the predicted values are higher than the measured values with about 20%, so there is a big difference between the predicted levels and the measured levels (Figure 7.65).

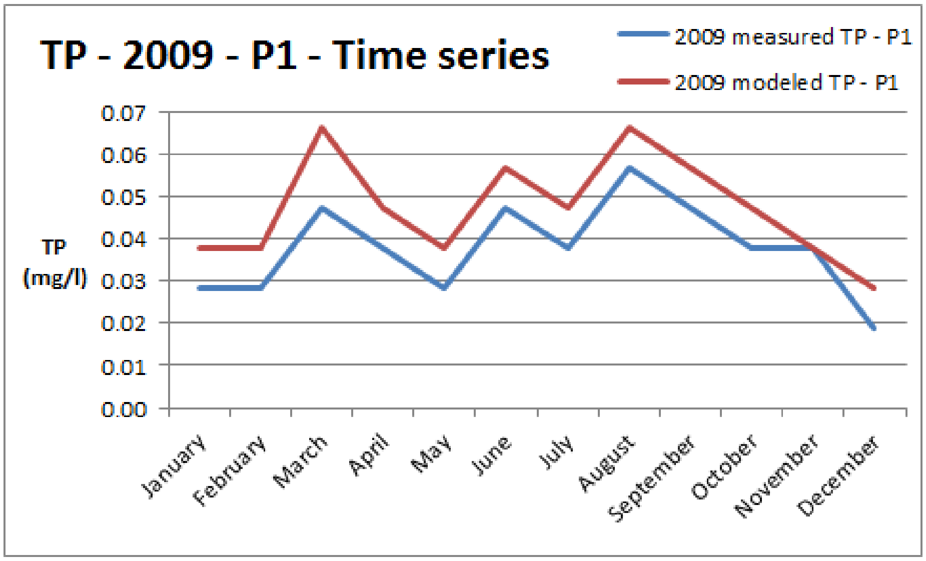


Figure 7.65. Time series for TP modeled and measured, 2009, in P1

In P2, the model very well predicted the TP levels, the correlation coefficient being over 0.9, as it is displayed in Figure 7.66.

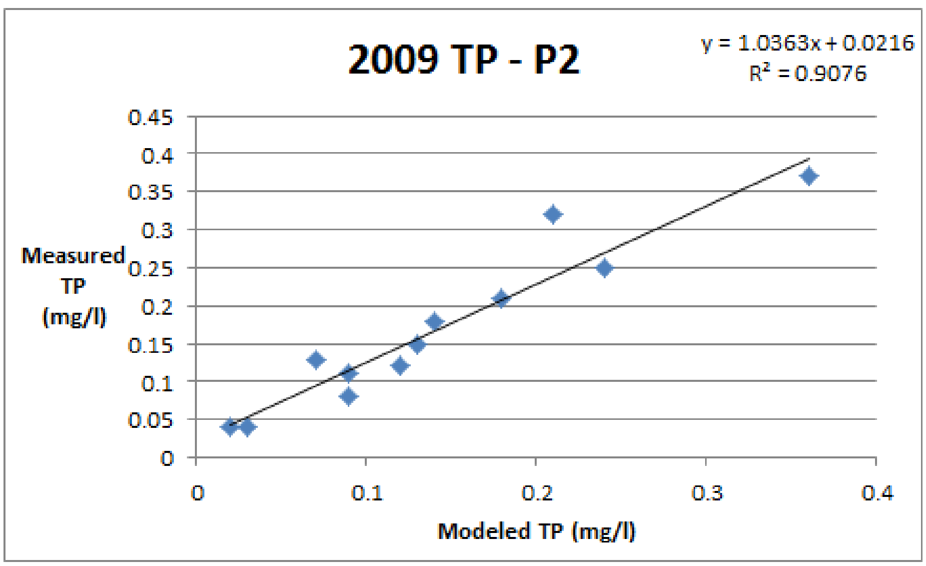


Figure 7.66. The correlation between the TP modeled and measured data, 2009, in P2

The predicted values followed the same trend as the measured data, but many of the predicted values were higher than the measured data with a percent of 2% for peak data until 20% for the low values of TP (Figure 7.67).

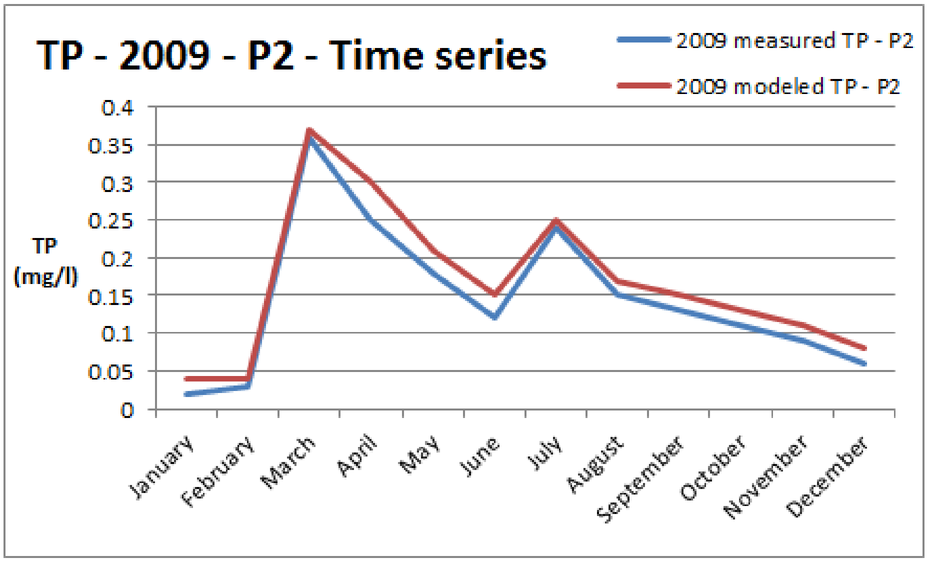


Figure 7.67. Time series for TP modeled and measured, 2009, in P2

In P3, the correlation between the measured and the modeled TP was very good, as well. It can be seen in the graph below (Figure 7.68)

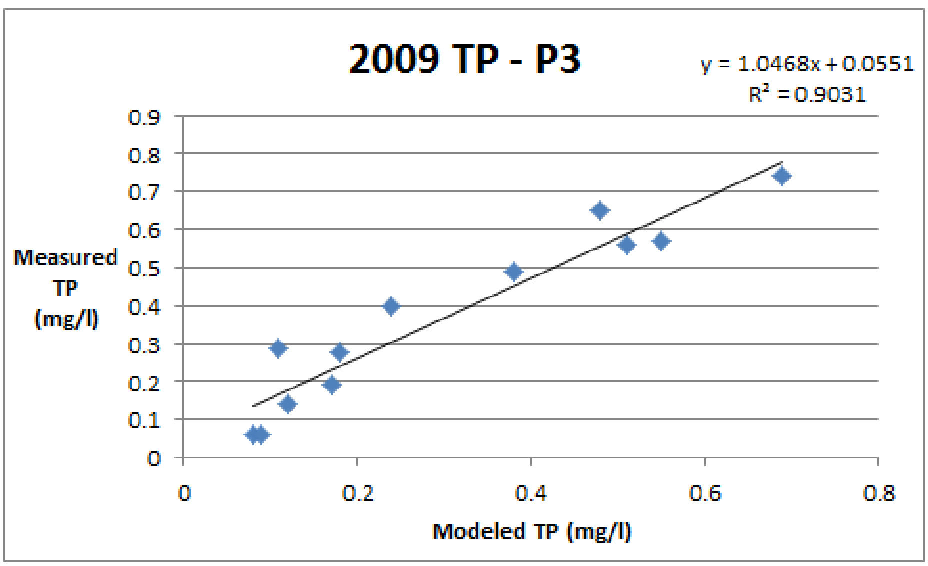


Figure 7.68. The correlation between the TP modeled and measured data, 2009, in P3

Good match between predicted and measured data was found in P4, in 2008, which is showed in Figure 7.69.

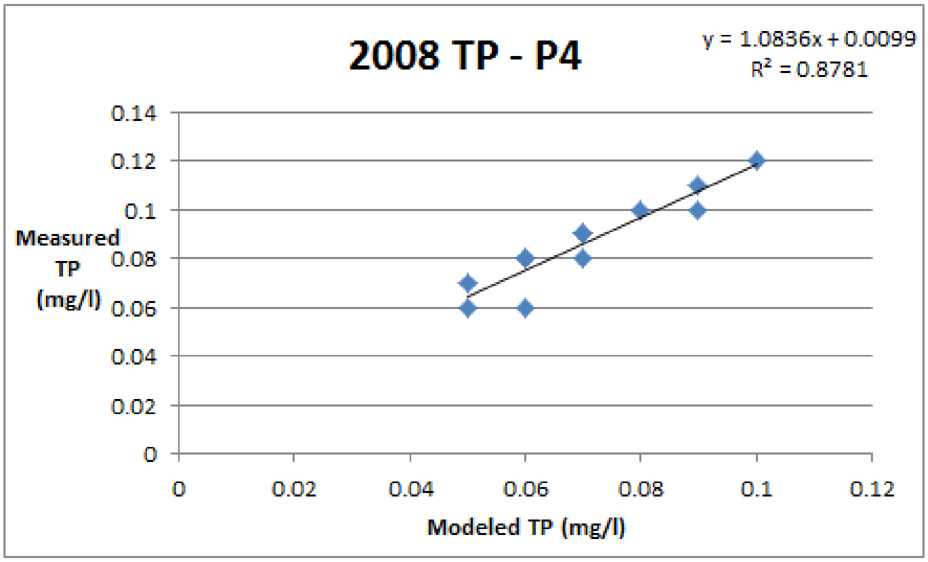


Figure 7.69. The correlation between the TP modeled and measured data, 2008, in P4

The correlation in P4 is better for 2009, where the impact of bushfires was evident (Figure 7.70)

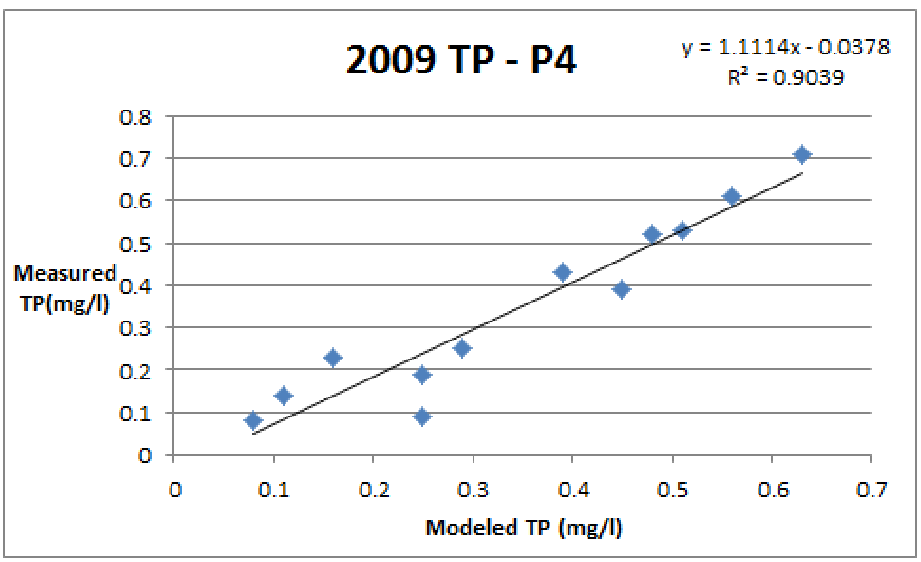


Figure 7.70. The correlation between the TP modeled and measured data, 2009, in P4

eWater was also able to predict very well the behaviour of TP in P5, as it is shown in Figure 7.71

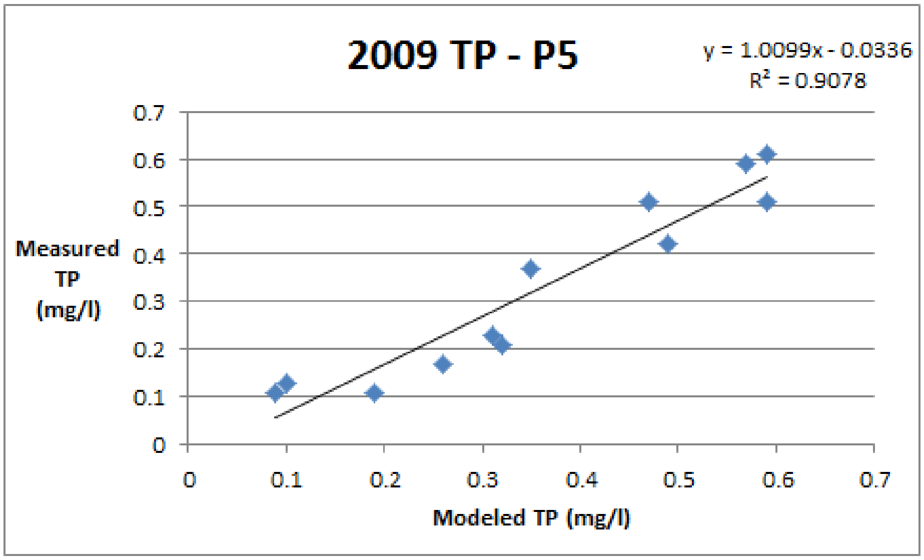


Figure 7.71. The correlation between the TP modeled and measured data, 2009, in P5

In the last point where the validation was done, the correlation between the predicted and the measured TP data was very good (Figure 7.72), so the model showed that it is able to successfully predict the TP levels in Latrobe catchment.

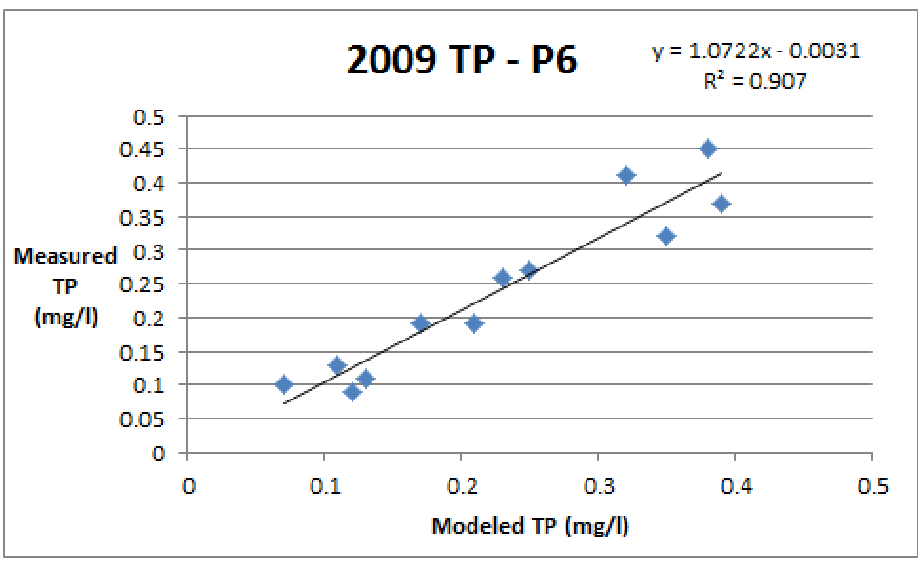


Figure 7.72. The correlation between the TP modeled and measured data, 2009, in P6

In general, the TP modeled data had the same trend as the measured data, but the values are overestimated (Figure 7.73). The peak values are overestimated with a quantity which in 2009 was less than 7%, which was very good, taking into account that the measured water quality date are monthly data.

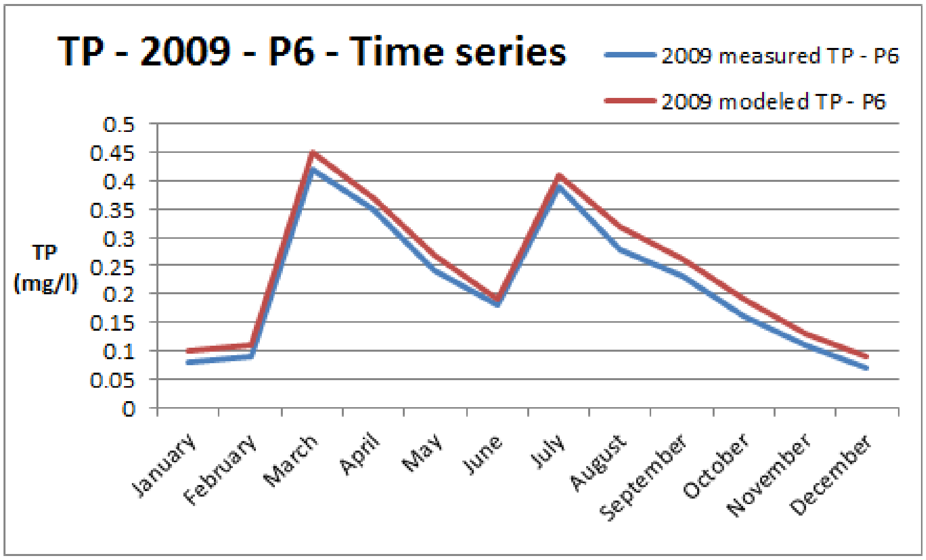


Figure 7.73. Time series for TP modeled and measured, 2009, in P6

Comparing the measured TP values recorded in 2009, and plotted in Figure 7.74, it can be noticed that the lowest TP values were recorded in P1, which means that P1 was not affected by the burnt areas, the burnt areas being downstream. Also, the higher TP values were recorded in P3, so the TP pollution entered in the stream in P3 was diluted until the end of catchment.

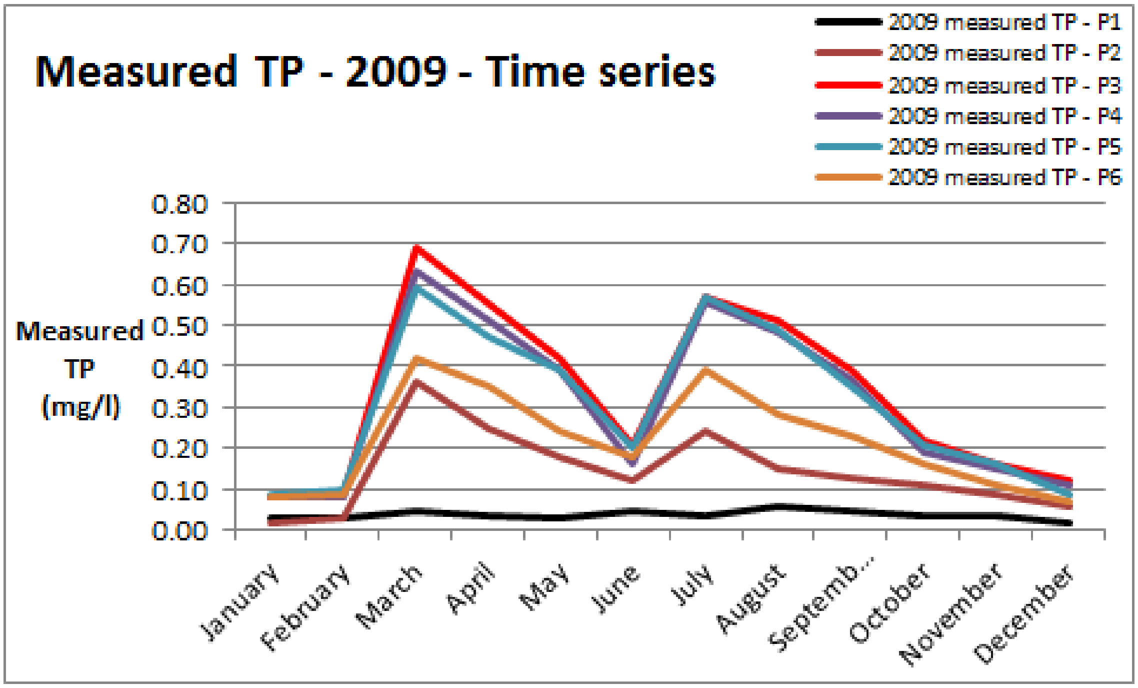


Figure 7.74. Time series for TP measured, 2009, in all the monitoring points

The modeled TP in the same points showed the same behaviour as the measured data (Figure 7.75), so the model well predicted the impact of bushfires on the TP levels in the catchment.

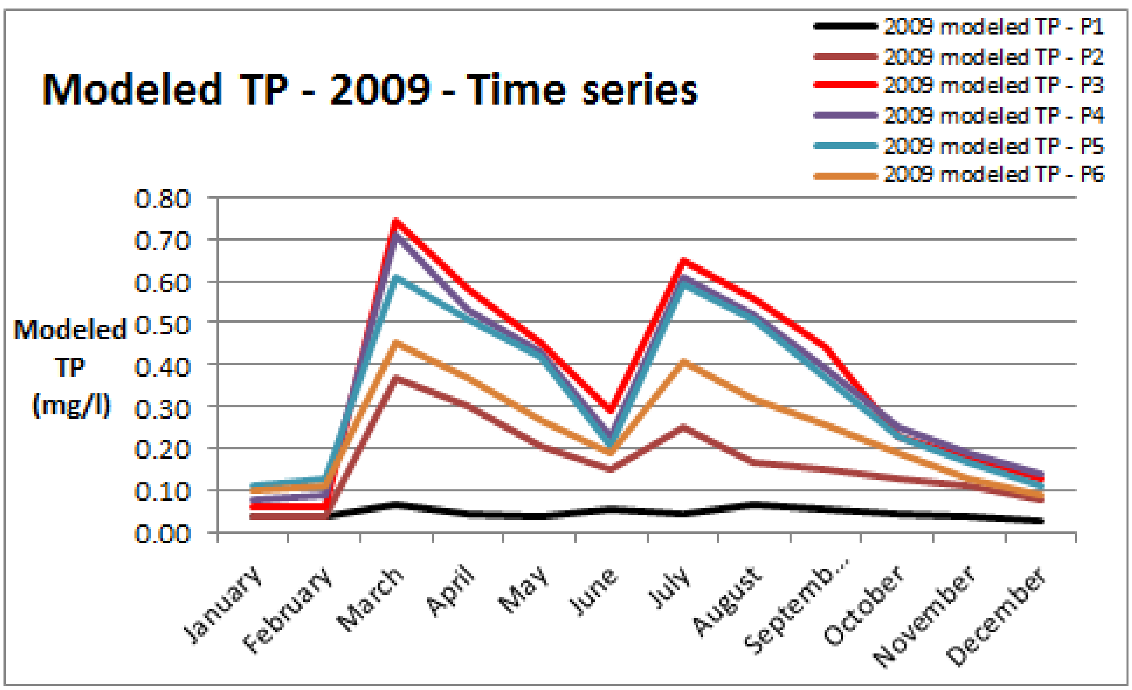


Figure 7.75. Time series for TP modeled, 2009, in all points where eWater was run

To analyse the time in which the TP pollution from bushfires disappeared from the catchment, a comparison between the measured data in P3, for all the study years (2008 to 2016) was done and was plotted in the graph below (Figure 7.76). From this graph, it can be seen that the highest pollution was recorded in 2009, which is correct, because in 2009, the bushfires were in the catchment, and the TP values are smaller, every year until 2014, when the TP levels became normal. So, the high levels of TP persisted 4 more years, except 2009.

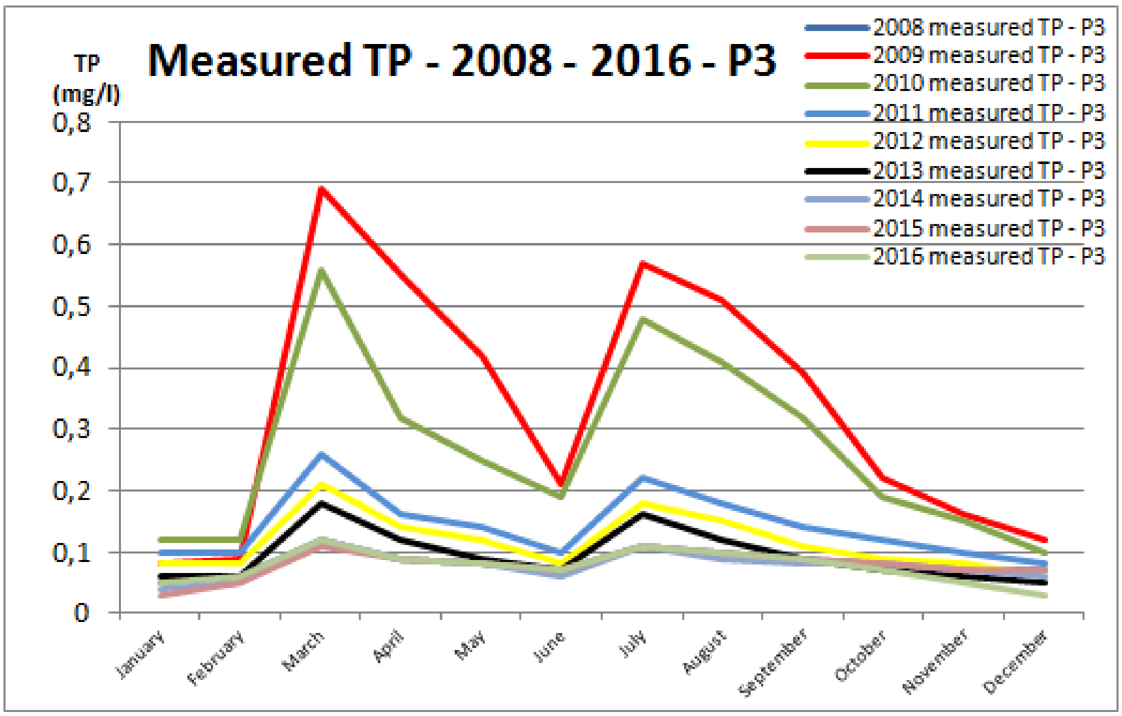


Figure 7.76. Time series for TP measured, in P3, for 2008-2016

The modeled data showed the same characteristic, so the model was able to correctly predict the TP levels over the next years after bushfires (Figure 7.77).

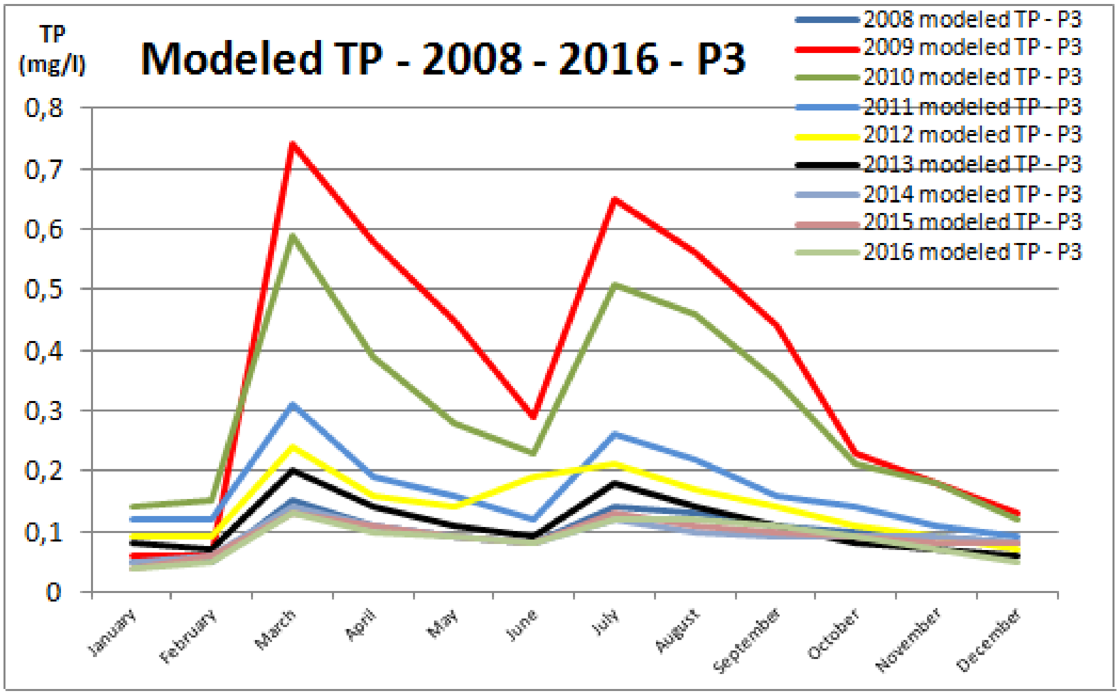


Figure 7.77. Time series for TP modeled, in P3, for 2008-2016

7.5. Conclusions

In this chapter, the empirical parameters for *eWater* model were found using the measured TSS, TN and TP data recorded in Point 7 from Latrobe catchment. Then, the model was validated using the data recorded in Poins 1 to 6, within the catchment.
The predicted values were very good correlated to the measured data, and followed almost the same trend.
Point 1 had low values of TSS, TN and TP, being situated upward to the burnt areas, so the bushfires did not affect this point.
The highest TSS values in 2009 were predicted in P5, and then in P6 the pollution was diluted, in perfect accord with the measured data. Not the same behaviour had TN and TP. The highest levels of TN and TP were predicted in P3, as the measured data showed, then the pollution slowly decreased, the smallest values being modeled in P6.
Also, the model was able to predict the impact of bushfires on TSS, TN and TP values in steams, over the next years. The TSS values were higher in 2009, when the

bushfires took place in Latrobe catchment, in 2010, the level decreased, then in 2011, they became normal, so after only one year, except 2009.

Related to the TN values, the highest levels were predicted in 2009, as it was expected, then the TN levels gradually decreased until 2011, then since 2012, the TN values became normal, so, the TN pollution persisted 2 years more after 2009.

The highest TP levels were recorded in 2009, when the bushfires were in the catchment, and the TP values are smaller, every year until 2014, when the TP levels became normal, so, the high levels of TP persisted in Latrobe catchment 4 more years, except 2009.

The model overestimated in all three cases: for TSS, TN and TP, the differences in values being between 2 and 20%.

This is good, because the model is able to predict the worst situation in terms of the catchment pollution. On the other hand, if the decision factors would spend money to solve the worst situation, maybe some other problems that came up in the council would remain unsolved because of the lack of money.

So the need to improve the model is mandatory.

8. THE IMPROVEMENT OF THE MODEL PARAMETERISATION, THE VALIDATION AND THE EVALUATION OF THE HYDROLOGICAL MODEL

8.1. Introduction

In Chapter 7, the eWater parameterisation was established, for all three water quality pollutants: TSS, TN and TP. The model was calibrated using the water quality values measured at P7 in the Latrobe catchment. P7 is the last monitoring point in the catchment, before the river leaves the catchment. Parameters were validated for six points, along the catchment. The correlation coefficients were above 0.7 for all years and all points, which means that the model reasonably predicted the TSS, TN and TP levels in the catchment. The trend of the modeled data followed the measured data, but the model overestimated for all three pollutants, the differences in values being between 2 and 20%.

In this chapter, a new landuse was taken into account and the empirical parameters for filter model (which is embedded in eWater) have slightly changed. The modeled data provided by *eWater* in this situation were very good correlated with the measured data. The correlation coefficients are higher than 0.9, and the modeled data has the same trend as the measured data. With these improvements, the model is able to predict very well the TSS, TN and TP levels in all 6 points within the Latrobe catchment.

8.2. Improvements in *eWater* parameterisation

Using the parameterisation established in Chapter 7, the model overestimated for all three pollutants taken into account. Changing the empirical parameters, the correlation coefficients between the modeled and the measured data became lower, and the modeled data did not follow the trend of the measured data. This means that there are other landuse types which have not been considered, that likely had big impact on pollution levels. Coal mining sites in the Latrobe catchment were considered at this stage. The map with all the landuse types and the coal mines can be seen in Figure 8.1.

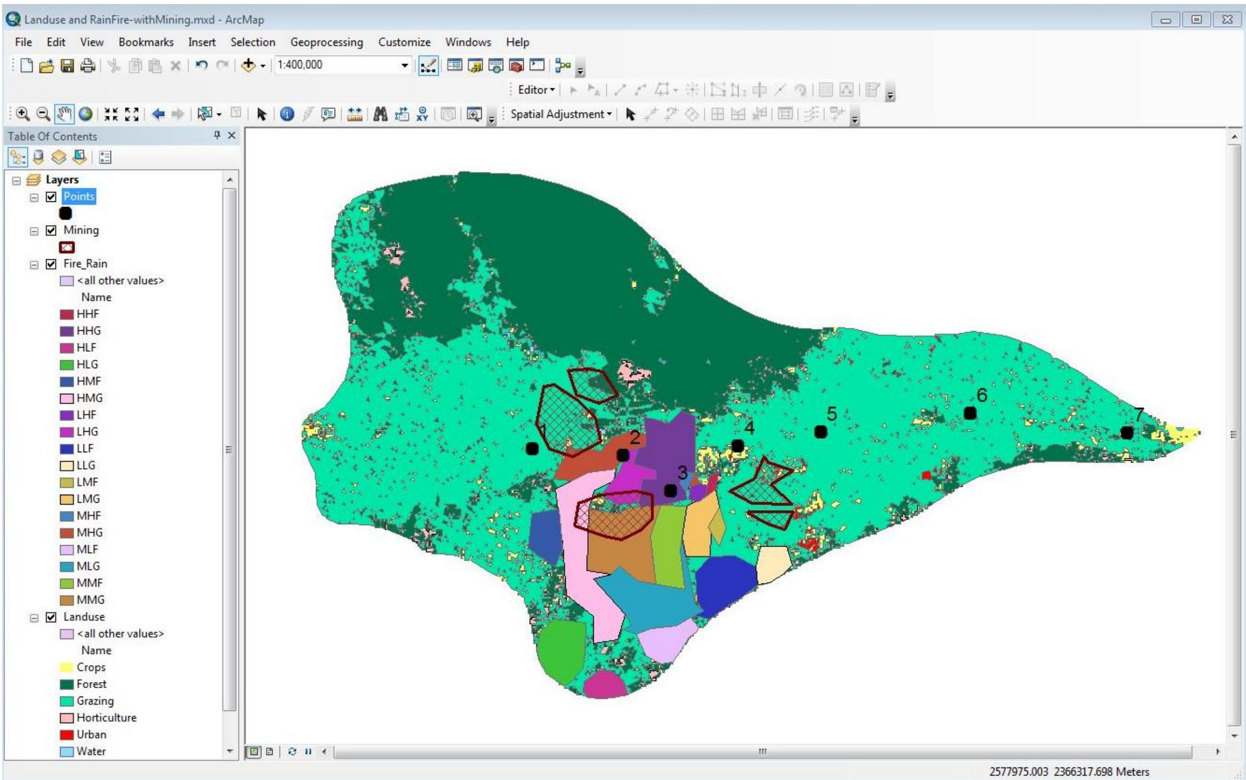


Figure 8.1. Latrobe catchment with all types of landuse including the coal mines

The values for the rainfall runoff model empirical parameters, which can be found in Table 7.6, remained unchanged. One more landuse was added: the coal mining landuse. After taking into account the mining, the model was run several times with various values of the empirical parameters and the outputs were analysed. The best simulated results were obtained for the empirical parameters (for rainfall runoff model) showed in Table 8.1:

X1 (mm)	X2 (mm)	X3 (mm)	X4 (h)
110	2	70	24

Table 8.1. The empirical parameters which correspond coal mining landuse

Also, for the constituent generation model, the empirical parameters The Event Mean Concentration (EMC) and the Dry Weather Concentration (DWC) for coal mining landuse are shown in Table 8.2:

Landuse	TSS	TN	TP
Coal mining landuse EMC	440	8.0	3.0
Coal mining landuse DWC	44	0.8	0.3

Table 8.2. The values for EMC and DWC for coal mining landuse

For the filter model, the empirical parameters were changed according to the Table 8.3. These values are applied for all types of landuse in the catchment.

FILTER MODEL PARAMETERS	TSS	TN	TP
BASE-FLOW PARAMETER	35	12	11
QUICK-FLOW PARAMETER	25	9	8

Table 8.3. The values of the filter model empirical parameters

8.3. The validation and evaluation of the hydrological model after considering the coal mining landuse

After improving the parameterisation, the data still showed higher levels of TSS, TN and TP after rain, and the TSS, TN and TP values are huge after a bushfire followed by rain. In all monitoring points, the correlation coefficients had values higher than 0.9, so the model, with this parameterisation, is able to predict very well the TSS, TN and TP pollution. The trends for the modeled and the measured data were the same in all points.

8.3.1. The validation and evaluation of the model for TSS

An example of correlation between the modeled and measured TSS for the monitoring Point 1, for 2008, is presented in Figure 8.2. The correlation coefficient is 0.9025, which represents a very good value.

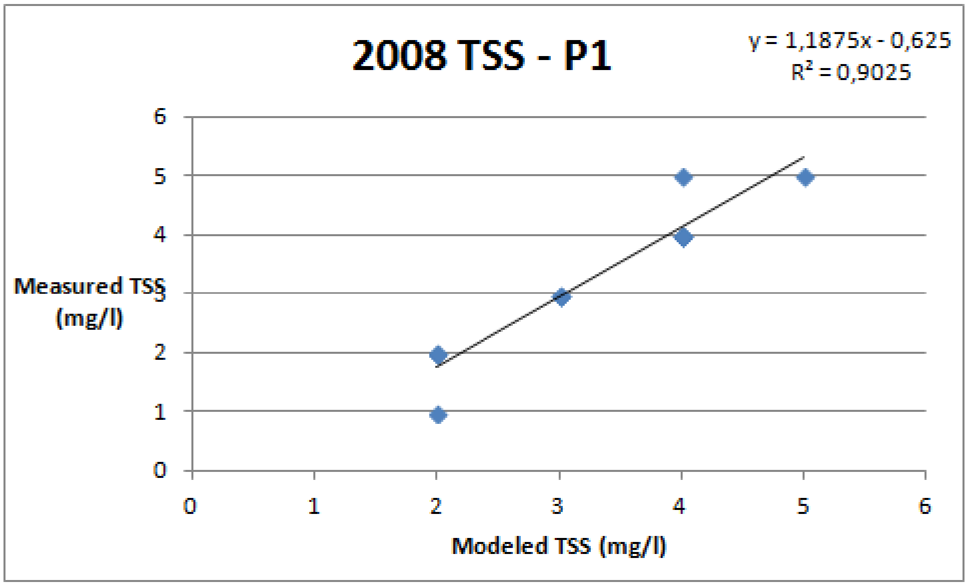


Figure 8.2. The correlation between the TSS modeled and measured in 2008, in P1

In P1, in 2009, the correlation coefficient is even better, as it can be seen in Figure 8.3. In this case, the correlation coefficient is 0.95, better compared with the value before the improvements, showed in chapter 7 part a, where it was found 0.8833.

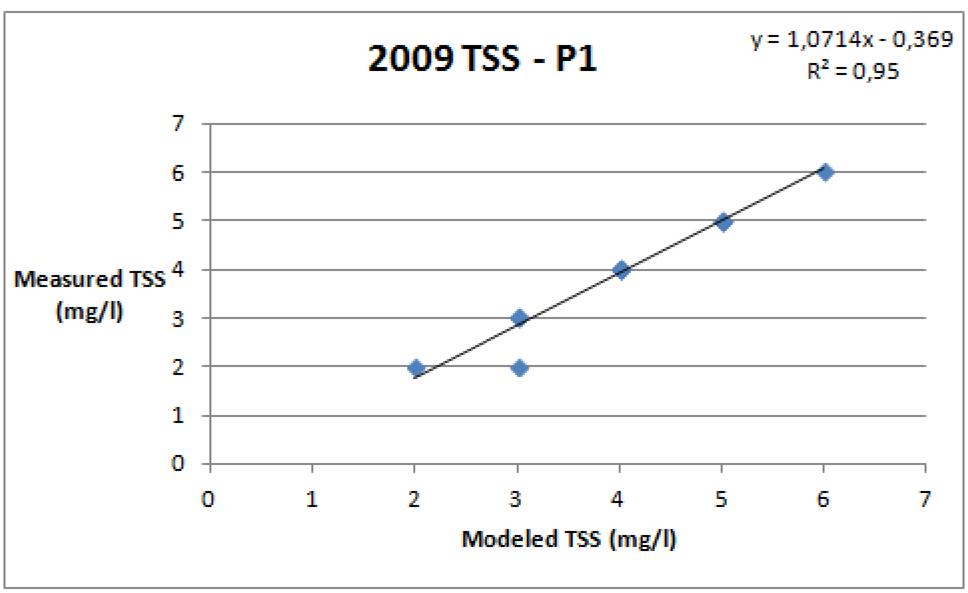


Figure 8.3. The correlation between the TSS modeled and measured in 2009, in P1

In Figure 8.4, the modeled and measured data show exactly the same trend, the only difference is in January, when the measured data is 3mg/l and the simulated data is 2mg/l. The water pollution actually starts when the bushfires start. The wind blows and some of the pollution from atmosphere is transported and settles on the water surface. This pollution cannot be taken into account by the model. After a period, the rain washes the burnt areas and the ash and debris are transported into streams. This pollution is taken into account by the model, and the modeled values of the pollutants become high and very well correlated with the measured data. This situation can be seen in all points in January 2009, when the bushfires occurred.

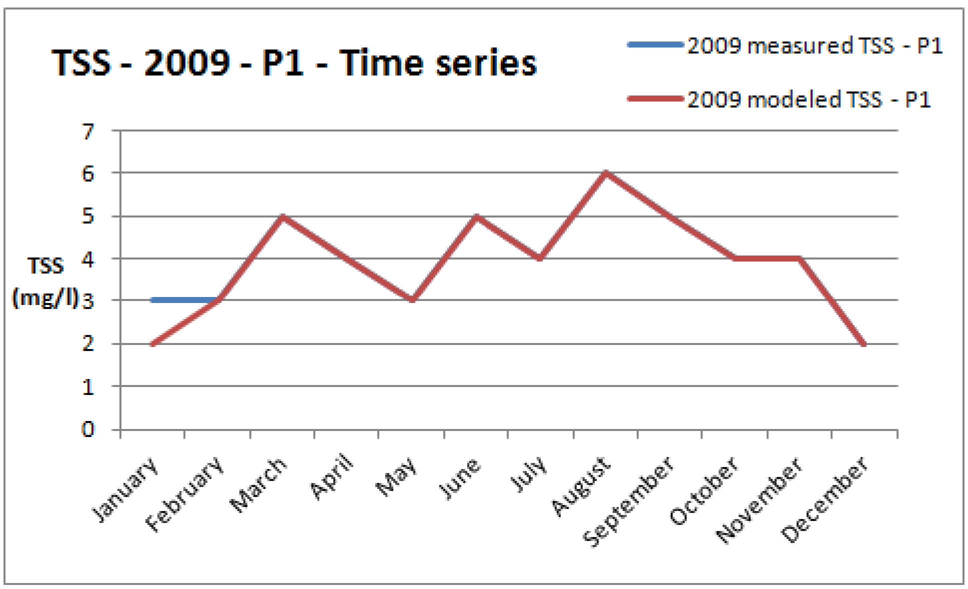


Figure 8.4. Time series for TSS, for both measured and modeled data, in 2009, in P1

In 2010, the correlation between the modeled and measured TSS is also very good. This is shown the figure Figure 8.5.

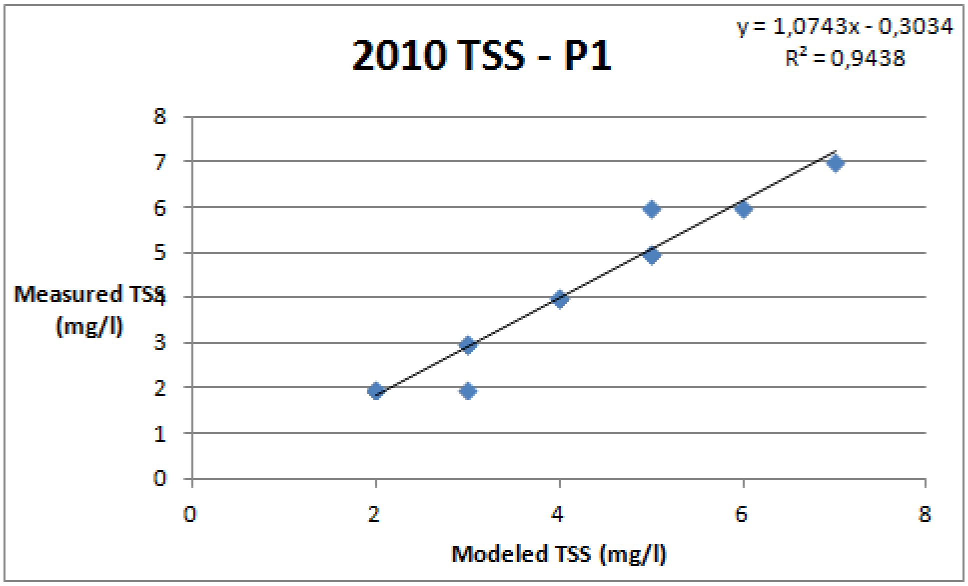


Figure 8.5. The correlation between the TSS modeled and measured in 2010, in P1

The correlations between the modeled and measured data are higher than 0.9 for P2, as well. Figure 8.6, displayed the correlation for 2008.

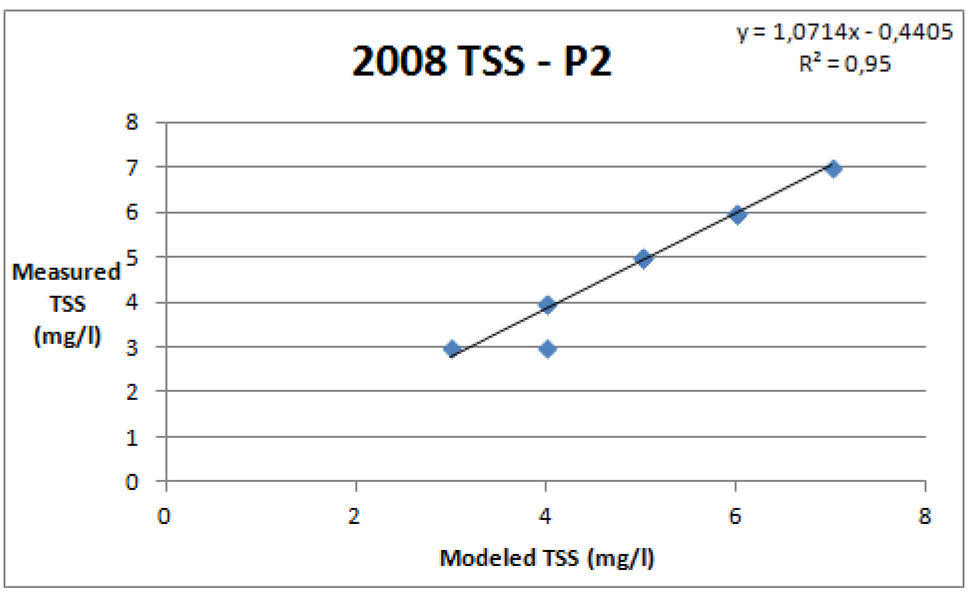


Figure 8.6. The correlation between the TSS modeled and measured in 2008, in P2

Very good correlation was recorded in P2, in 2009, so the model is able to predict very well the TSS values after bushfires. The scatter graph was plotted in the figure below (Figure 8.7).

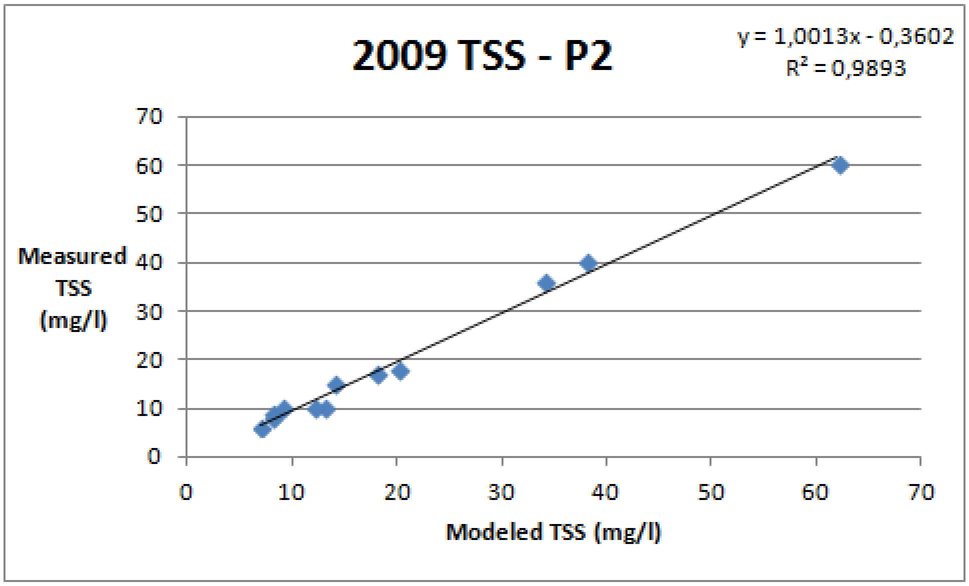


Figure 8.7. The correlation between the TSS modeled and measured in 2009, in P2

Figure 8.8 shows the trend of the measured and modeled data. The high TSS peak in March 2009, resulted from the bushfires pollution, is very well expressed in the modeled data. The modeled data followed very close the measured data. The model did not overestimate. It predicted very well the TSS values after bushfires, in P2.

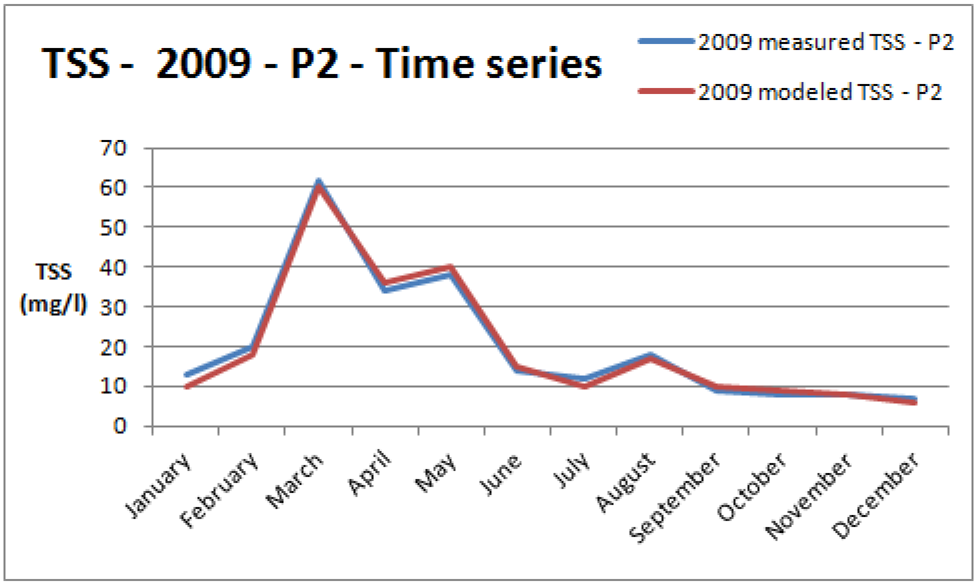


Figure 8.8. Time series for TSS, for both measured and modeled data, in 2009, in P2

The correlation coefficient between the TSS modeled and measured for Point 2, 2010 was plotted in Figure 8.9. The value is higher than 0.9, which means that the correlation between the measured and the modeled data is very good.

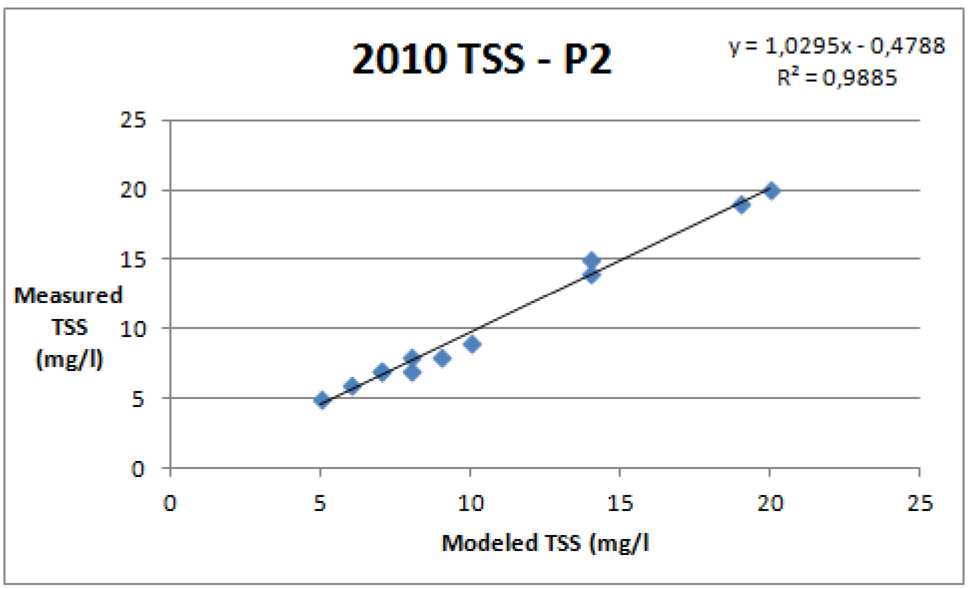


Figure 8.9. The correlation between the TSS modeled and measured in 2010, in P2

In P3 was also found a very good correlation, the model being able to predict very well the TSS values in this point, as well.

In figure below (Figure 8.10) it is represented the correlation between the TSS modeled and the TSS measured in 2009, in P3. The correlation coefficient between the modeled and the measured data increased from 0.7860 to 0.9986, after introducing in the model the mining sites as separate landuse.

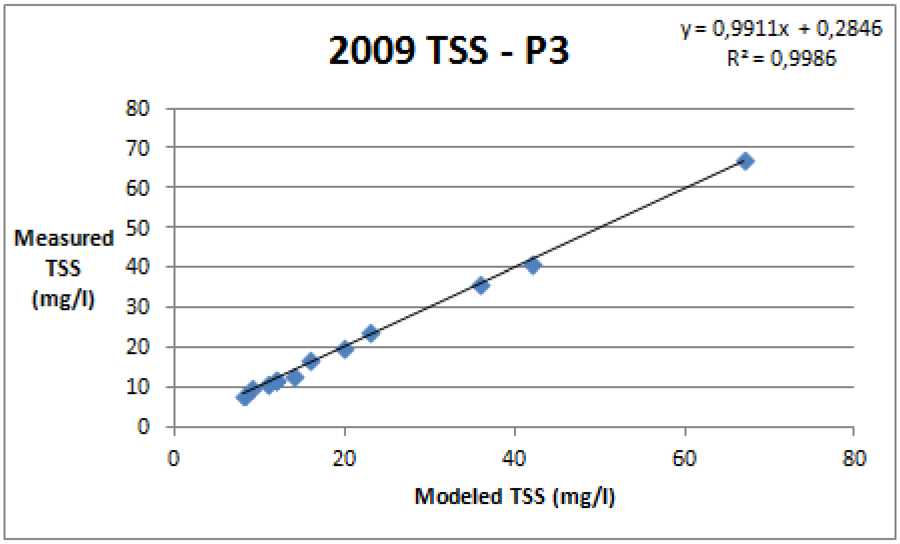


Figure 8.10. Correlation between TSS modeled and measured data in 2009, in P3

The modeled and measured data behave in the same way, as it can be seen in the figure 8.11.

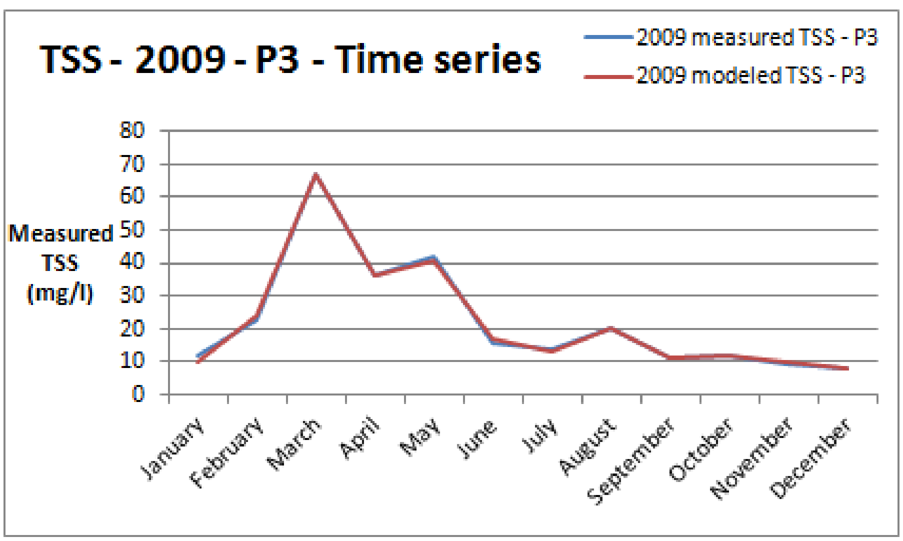


Figure 8.11. Time series for TSS, for both measured and modeled data, in 2009, in P3

Another good example of improvement is the correlation between TSS modeled and measured data for 2010, in P3, plotted in Figure 8.12.

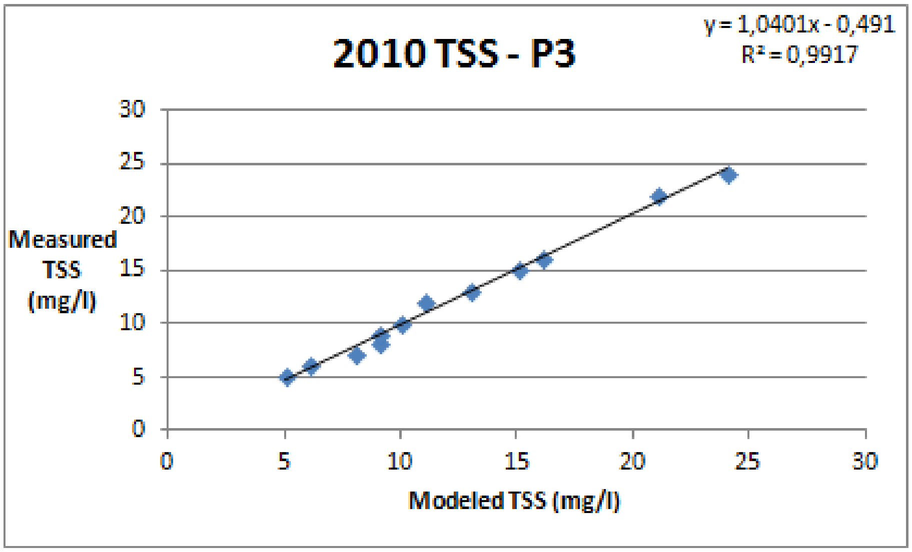


Figure 8.12. Correlation between TSS modeled and measured data in 2010, in P3

In Point 4, 2008, the correlation between the modeled and the measured TSS increased from 0.8894 to 0.9752, as it is represented in Figure 8.13.

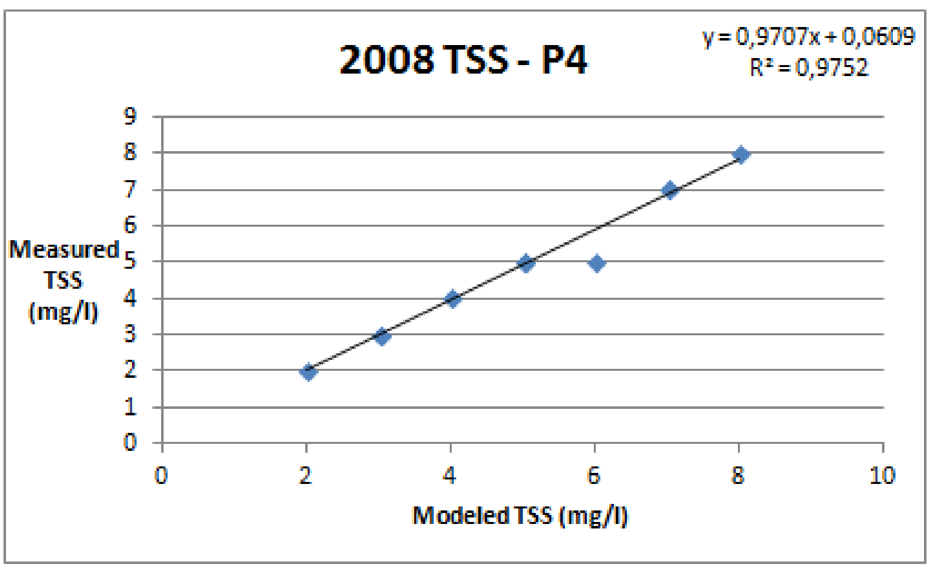


Figure 8.13. Correlation between TSS modeled and measured data in 2008, in P4

A better correlation coefficient was obtained after the introducing of mines landuse in P4, in 2009, when the bushfires occurred in the region (Figure 8.14), so the model predicted very well the TSS, especially after bushfires.

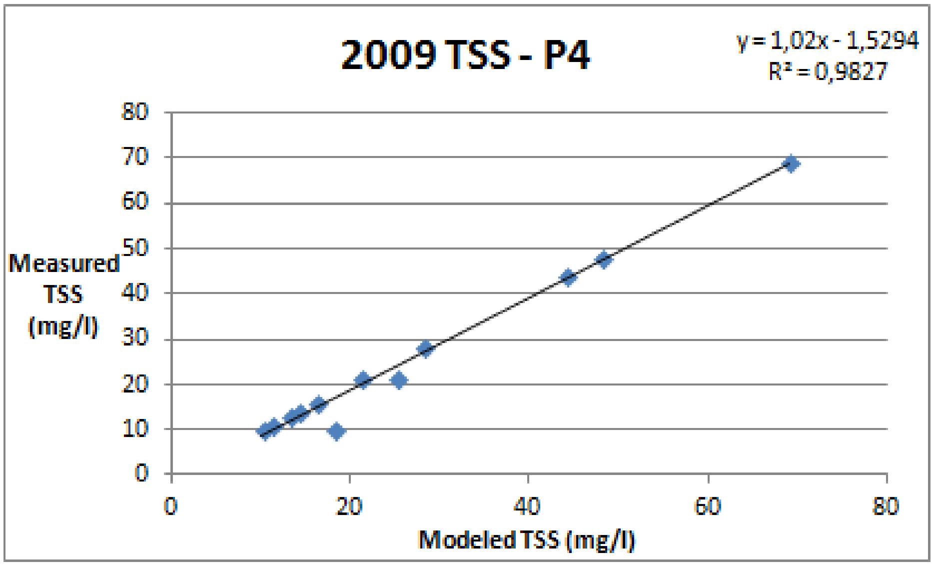


Figure 8.14. Correlation between TSS modeled and measured data in 2009, in P4

In Figure 8.15, the time series for both modeled and measured data for TSS in Point 4, in 2009 were plotted. Except the beginning of the year (January and February), the behaviours of modeled data and the measured data are the same.

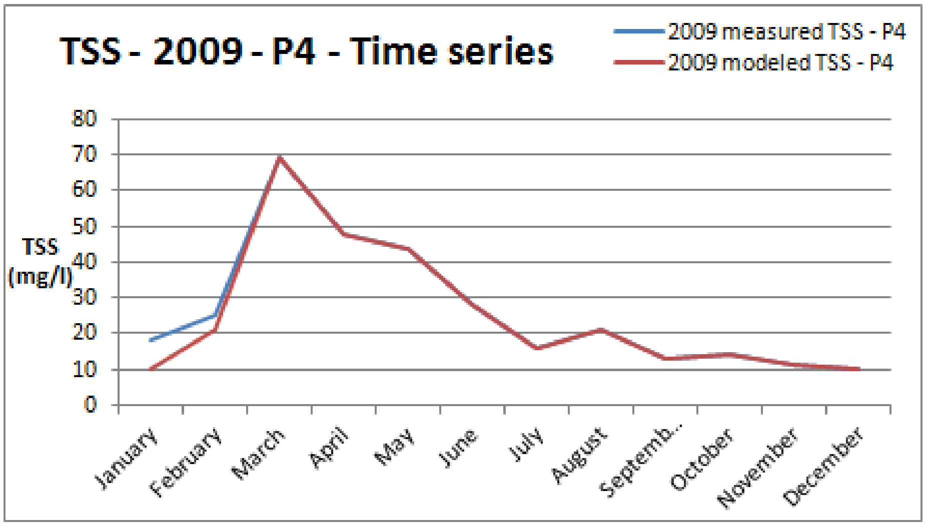


Figure 8.15. Time series for TSS, for both measured and modeled data, in 2009, in P4

In P5, in 2009, the same behaviour of the data can be noticed. The time series for modeled and measured data are plotted in the figure bellow (Figure 8.16).

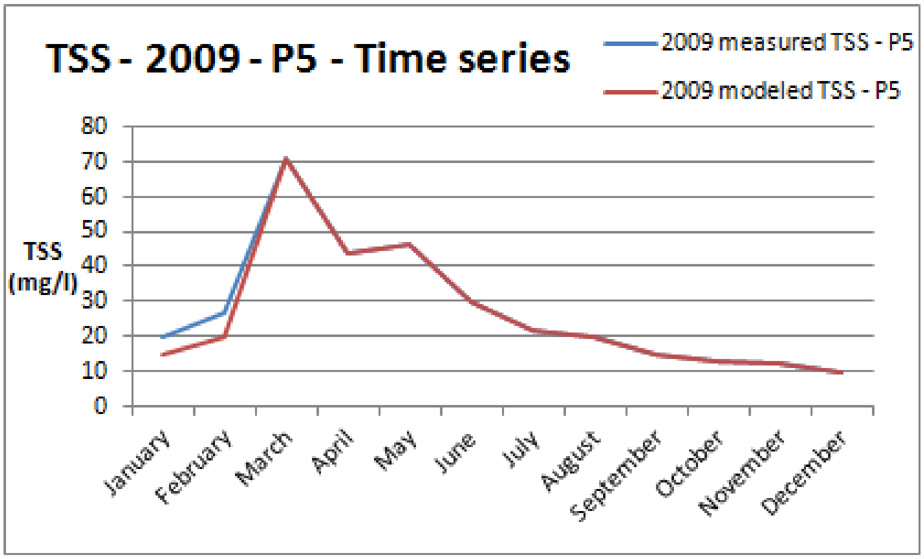


Figure 8.16. Time series for TSS, for both measured and modeled data, in 2009, in P5

The correlation coefficient between the modeled and the measured data in P5, in 2009 can be seen displayed in the graph below (Figure 8.17).

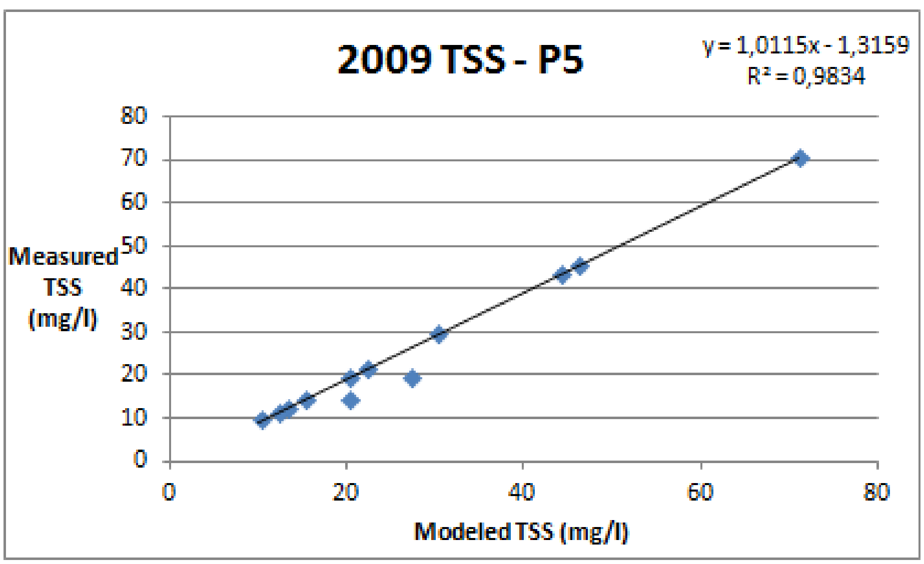


Figure 8.17. Correlation between TSS modeled and measured data in 2009, in P5

In P6, very good correlation between the modeled and the measured data was found. The graph below (Figure 8.18) shows a correlation coefficient of 0.9946, which is better than the correlation coefficient obtained before considering the mines landuse (of 0.8722).

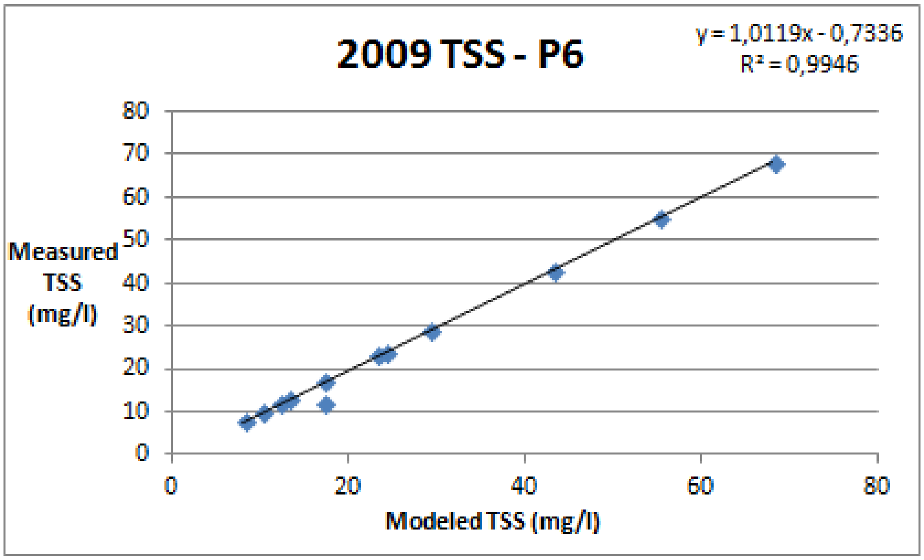


Figure 8.18. Correlation between TSS modeled and measured data in 2009, in P6

The modeled data has the same trend as the measured data, which means that the model is able to predict very well the TSS pollution in P6. After introducing the mines landuse, the accuracy of the estimation increased, so the model does not overestimate the pollution anymore. The modeled data are very closed by the measured data, so the model outputs are very reliable. This is displayed in Figure 8.19.

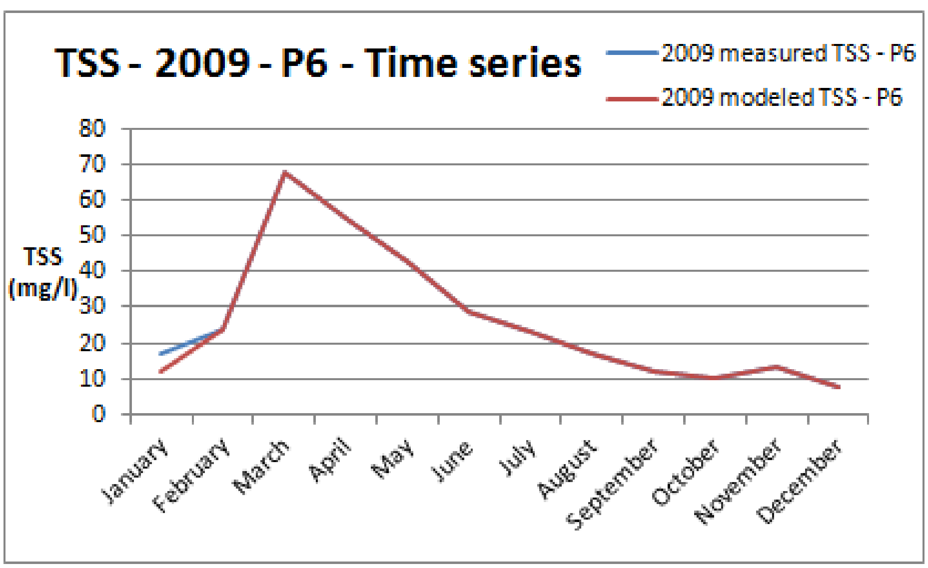


Figure 8.19. Time series for TSS, for both measured and modeled data, in 2009, in P6

8.3.2. The validation and evaluation of the model for TN

Inputing a new landuse into the model, which represents the mines sites improved the accuracy of the modeled TN, as well.

In Figure 8.20, the correlation between the modeled and the measured data in 2008, in P1 is plotted. The correlation coefficient is 0.933, better than the correlation coefficient before considering the mines landuse, which was 0.8047 (displayed in Figure 7.38)

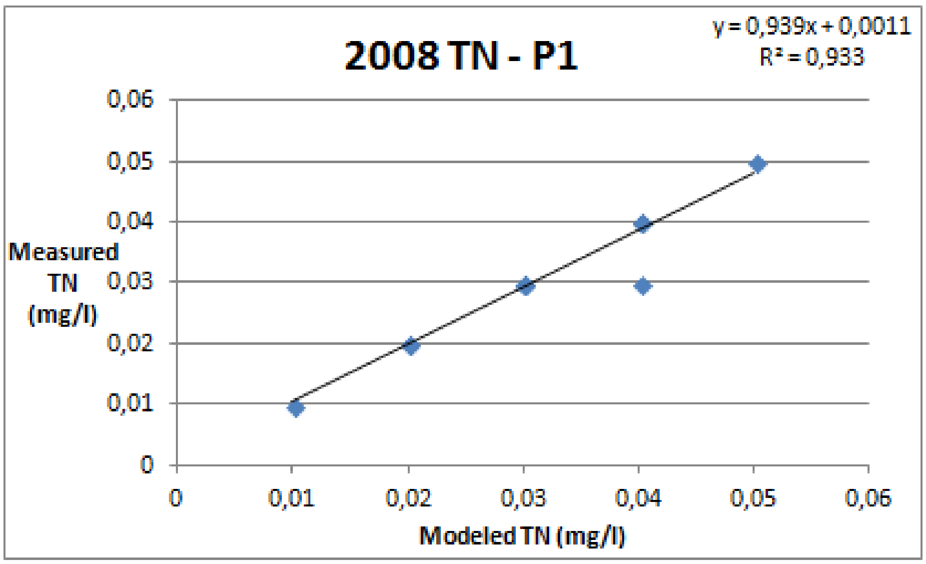


Figure 8.20. Correlation between TN modeled and measured data in 2008, in P1

The correlation between the modeled and the measured TN in 2009 is even better, so the model is able to estimate very well the TN concentrations after bushfires (Figure 8.21).

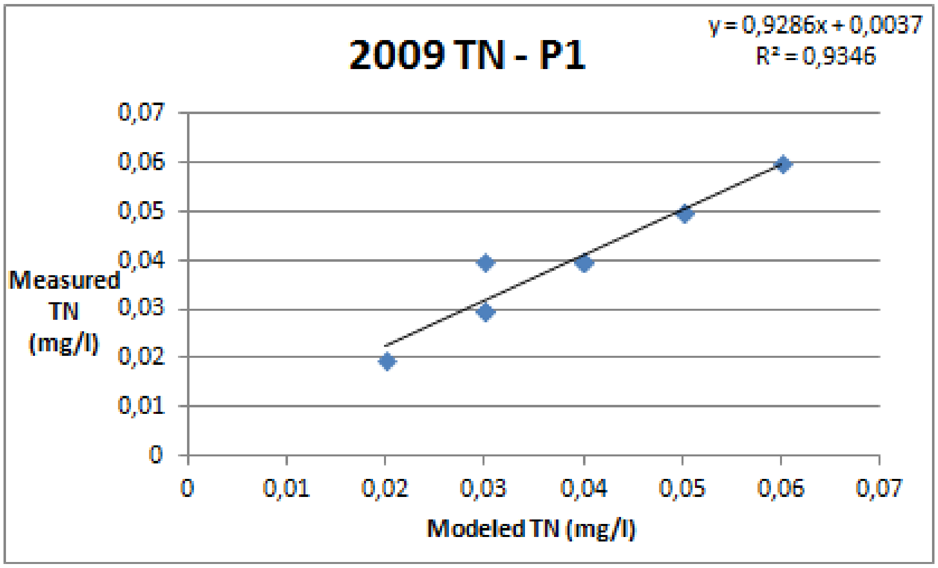


Figure 8.21. Correlation between TN modeled and measured data in 2009, in P1

Figure 8.22 shows the behaviours of the modeled and the measured data. Except the period between the starting of bushfires and the starting of rain in the catchment, when the measured data had higher values compared to the modeled data, the modeled data followed the same trend as the measured data, in P1.

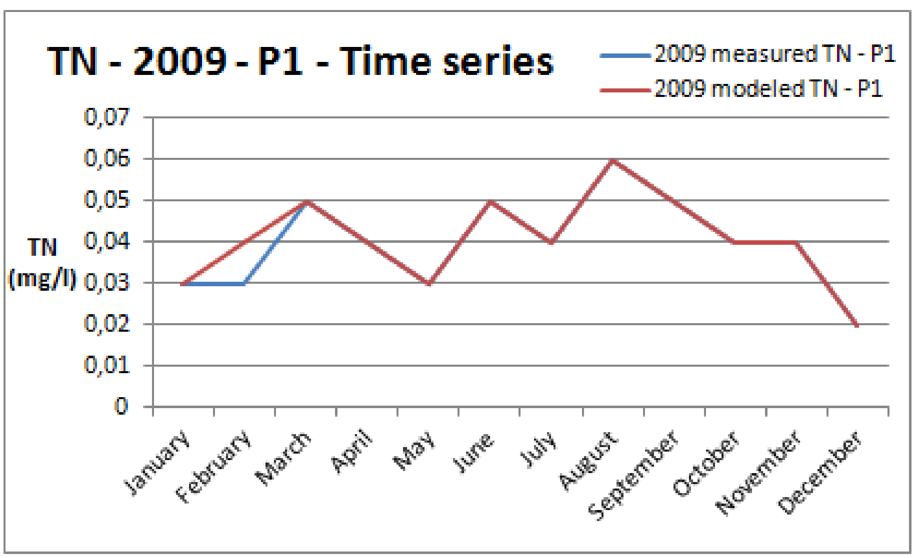


Figure 8.22. Time series for TN, for both measured and modeled data, in 2009, in P1

Very good correlation between the measured and the modeled data was found in P2 as well. The graph below (Figure 8.23) shows the data collected and modeled for 2008.

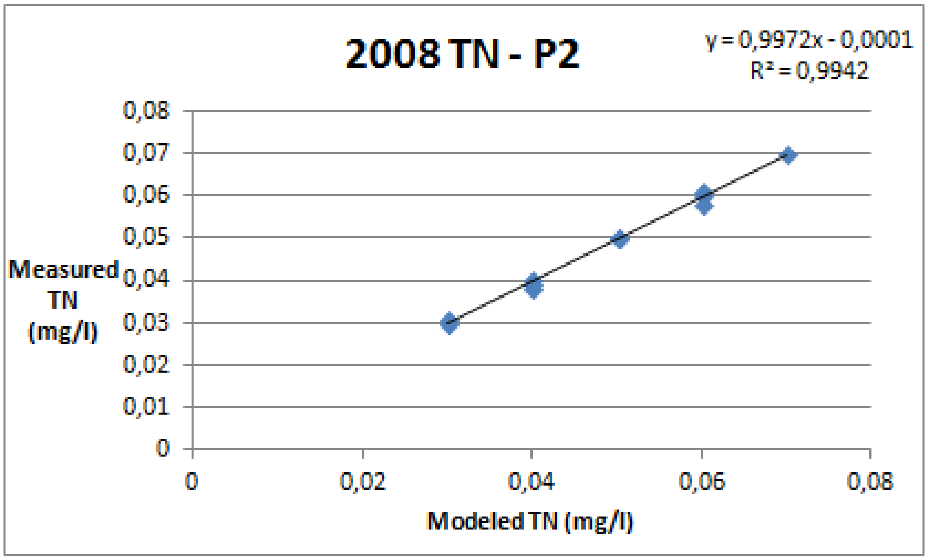


Figure 8.23. Correlation between TN modeled and measured data in 2008, in P2

It can be noticed that the correlation coefficient in 2009 is higher compared to the correlation coefficient found for 2008, as it can be seen in Figure 8.24. The model very well estimated the TN concentrations after bushfires.

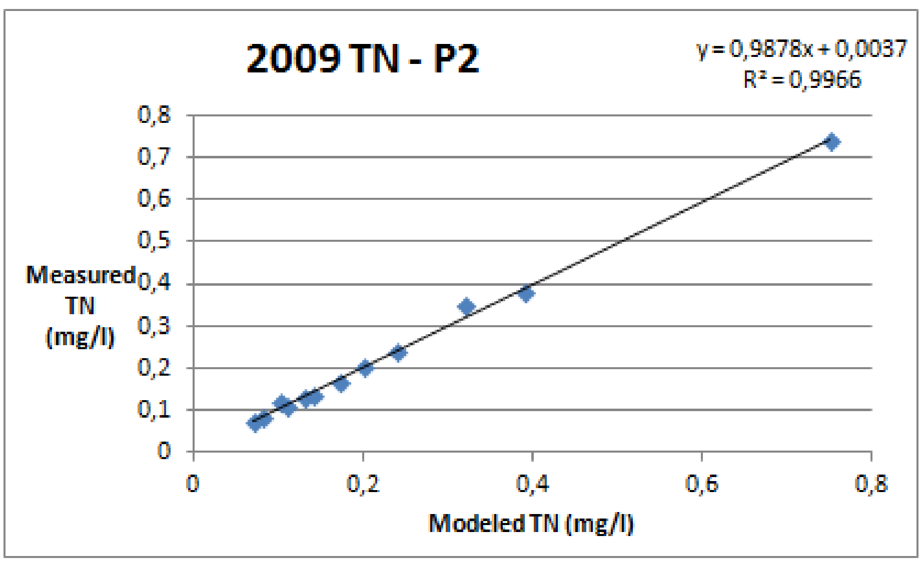


Figure 8.24. Correlation between TN modeled and measured data in 2009, in P2

The time series below (Figure 8.25) show a very good match between the modeled data and the measured data in P2, in 2009, after bushfires.

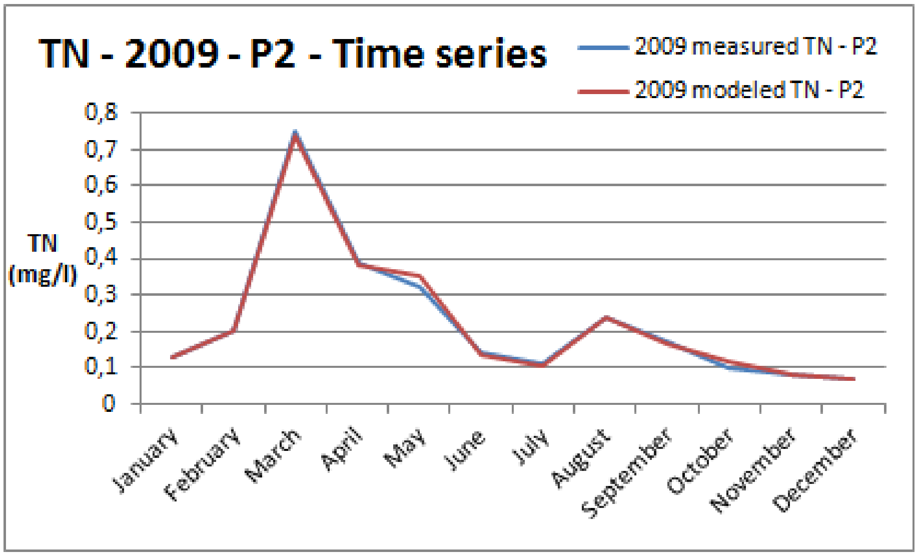


Figure 8.25. Time series for TN, for both measured and modeled data, in 2009, in P2

The higher levels of TN were found in P3 (Chapter 7.4.2). The chart displayed in Figure 8.26 shows a very good correlation between the modeled and the measured data. The correlation coefficient of 0.9981 is the highest compared to the correlation coefficients obtained in the other 5 points.

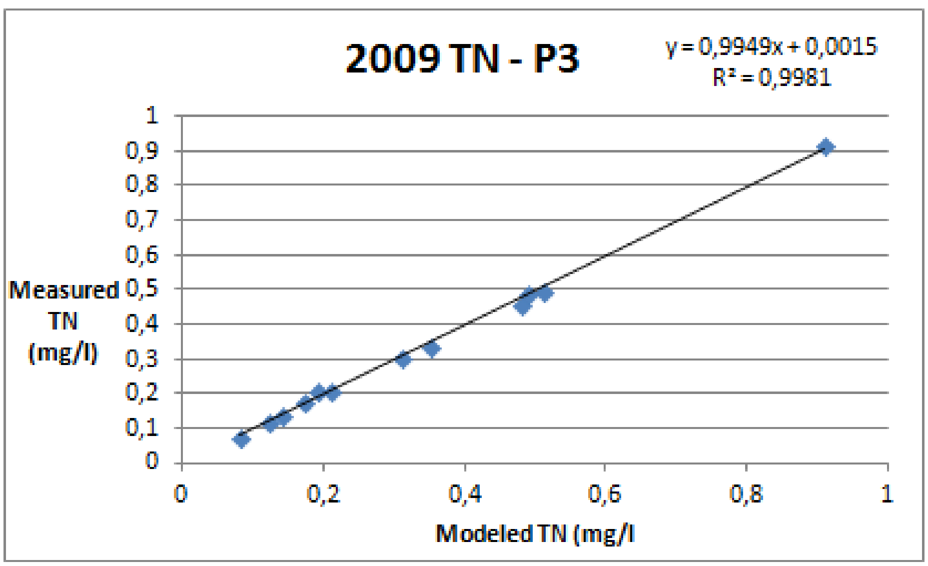


Figure 8.26. Correlation between TN modeled and measured data in 2009, in P3

In P3, the modeled data had the same behaviour as the measured data in 2009, which is displayed in Figure 8.27.

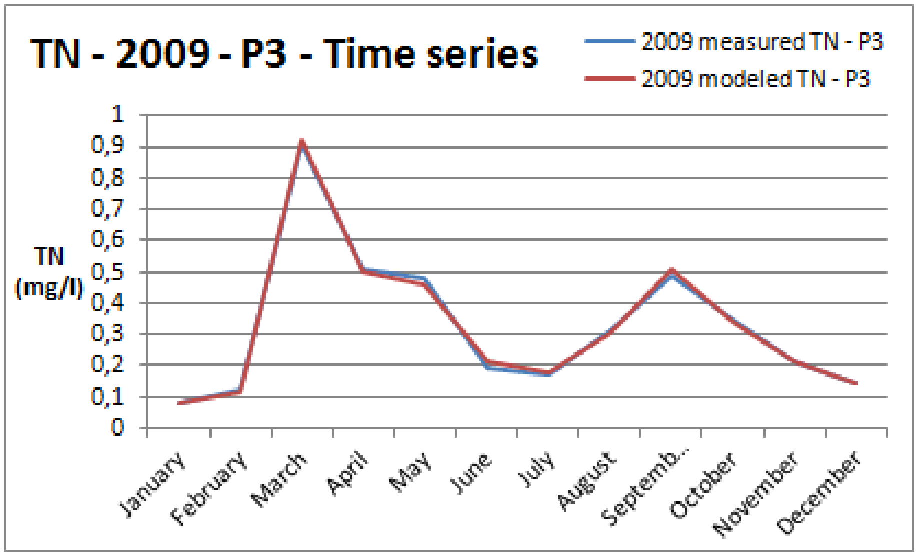


Figure 8.27. Time series for TN, for both measured and modeled data, in 2009, in P3

A very good correlation between the modeled TN and the measured data was found in P4, as well. The scatter graph below (Figure 8.28) was drawn for 2009, the year where the bushfires occurred in Latrobe catchment. The correlation coefficient is higher than 0.99, which means that *eWater* model very well estimates the TN concentrations after bushfires, in P4.

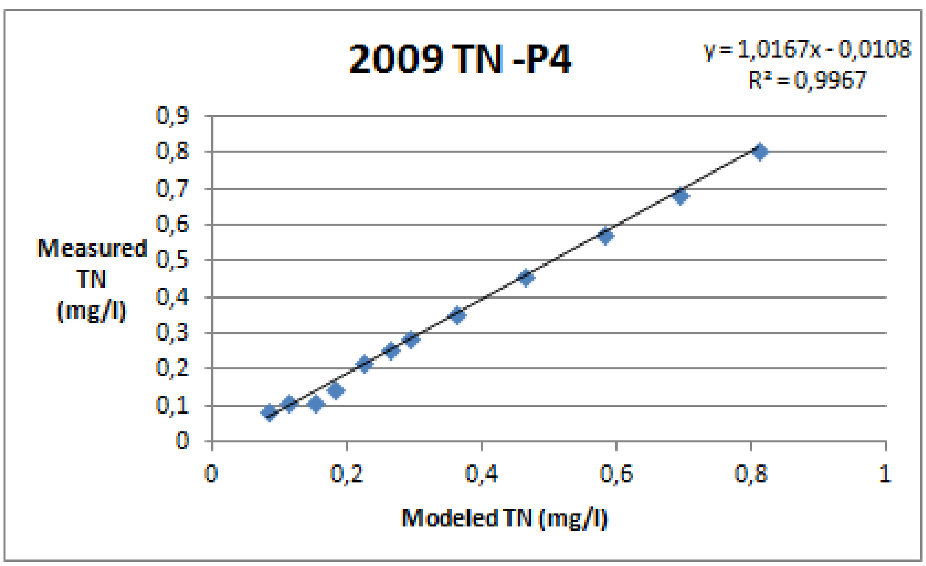


Figure 8.28. Correlation between TN modeled and measured data in 2009, in P4

In Figure 8.29, the time series of the modeled and measured TN in 2009, in P4 are plotted. The measured data in January and February are slightly higher than the modeled data, but for the rest of the year 2009, the modeled TN data perfectly fit the measured TN data.

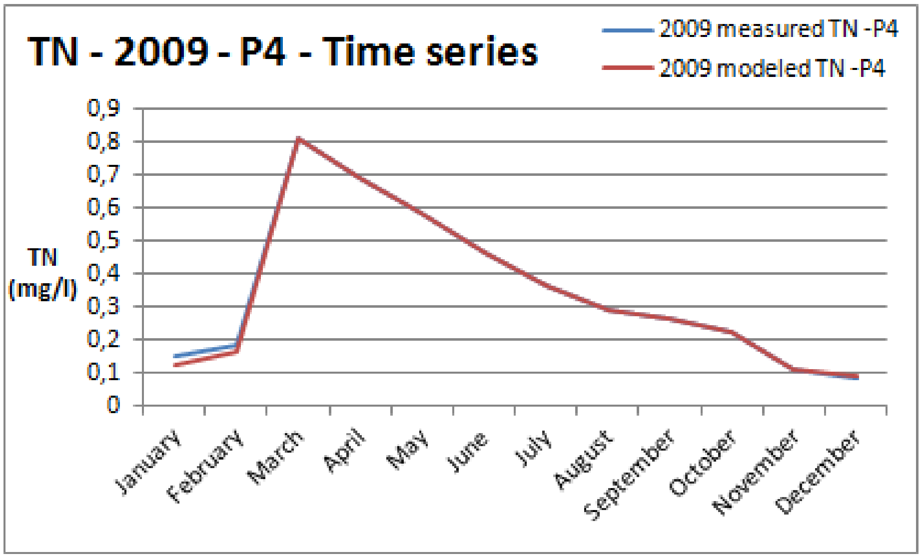


Figure 8.29. Time series for TN, for both measured and modeled data, in 2009, in P4

Another example which is displayed in Figure 8.30, is the correlation between the modeled and the mesured TN in 2009, in P5. The model predicted very well the TN pollution in this point, the correlation coefficient being very high (0.9974).

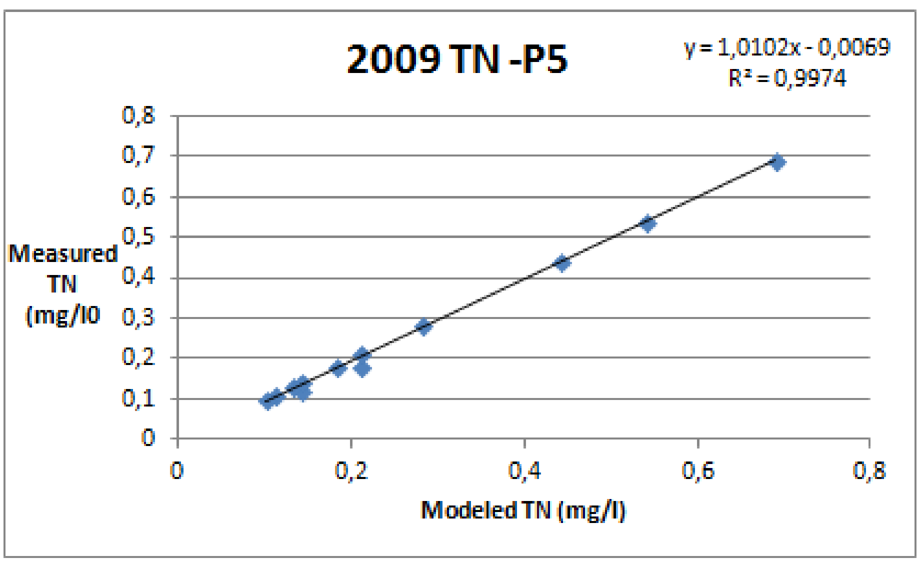


Figure 8.30. Correlation between TN modeled and measured data in 2009, in P5

The same behaviour of the modeled data in January – February was found in P5: the measured TN values are slightly higher than the modeled data (Figure 8.31).

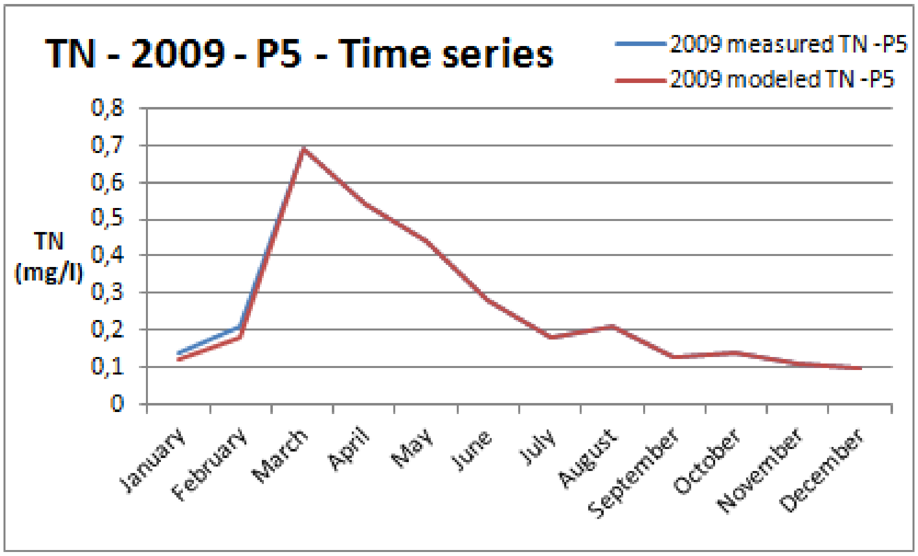


Figure 8.31. Time series for TN, for both measured and modeled data, in 2009, in P5

The model very well estimated the TN levels in point P6, as it can be seen in Figure 8.32. This is the example for year 2009, which is representative, because then the bushfires burnt large areas in Latrobe catchment.

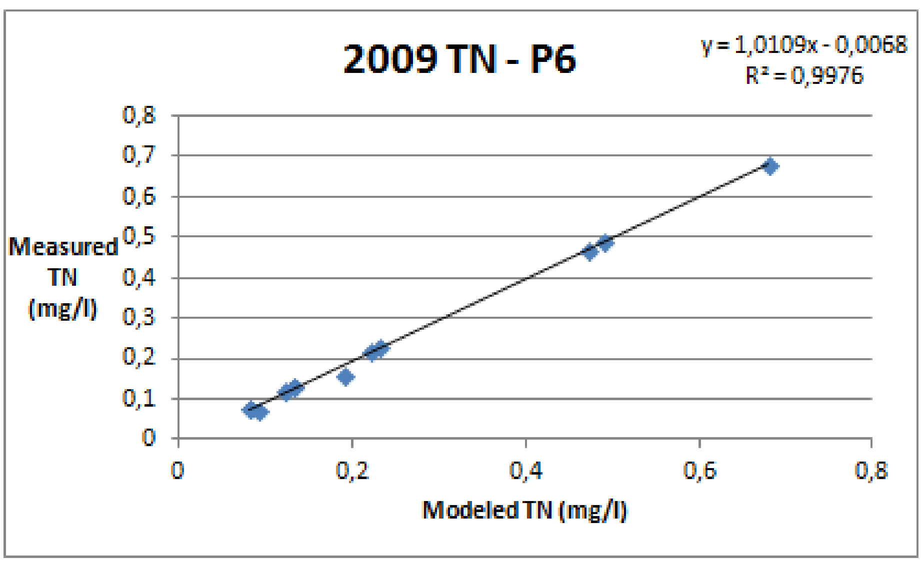


Figure 8.32. Correlation between TN modeled and measured data in 2009, in P6

Analysing the time series for modeled and measured TN in P6, in 2009, the same behaviour was found: the measured data in January and February are slightly higher than the modeled data (Figure 8.33). In that period, the bushfires started to burn various areas in Latrobe catchment, and some ash was transported by the winds toward the streams, pollution which was not taken into account by eWater. The difference between the modeled and the measured data in that period is about 0.05%.

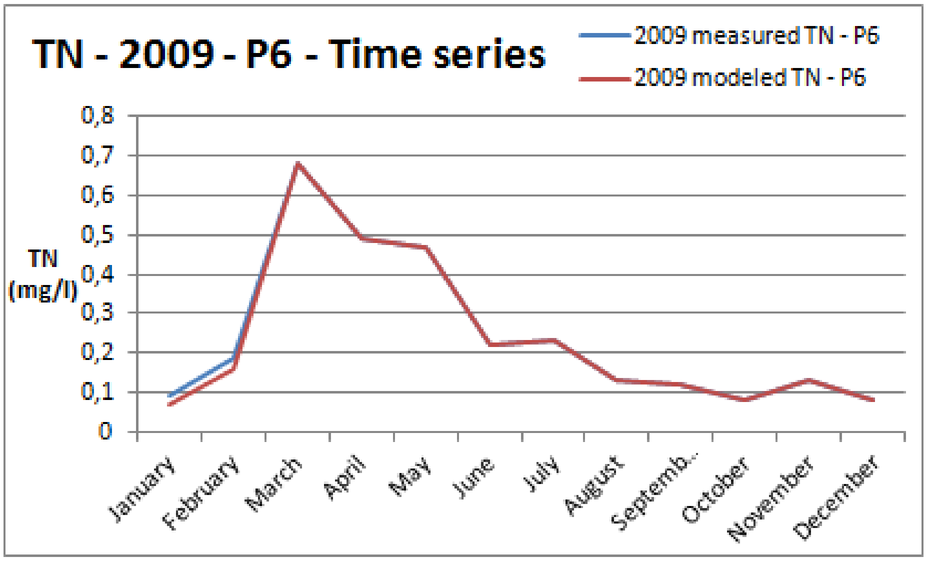


Figure 8.33. Time series for TN, for both measured and modeled data, in 2009, in P6

8.3.3. The validation and evaluation of the model for TP

Introducing in *eWater* the coal mining as a landuse led to a better correlation between the modeled and the measured TP for all years and all points in Latrobe catchment. In all cases, the correlation coefficient is higher than 0.9.

In Figure 8.34 is an example of correlation for 2009, for P1.

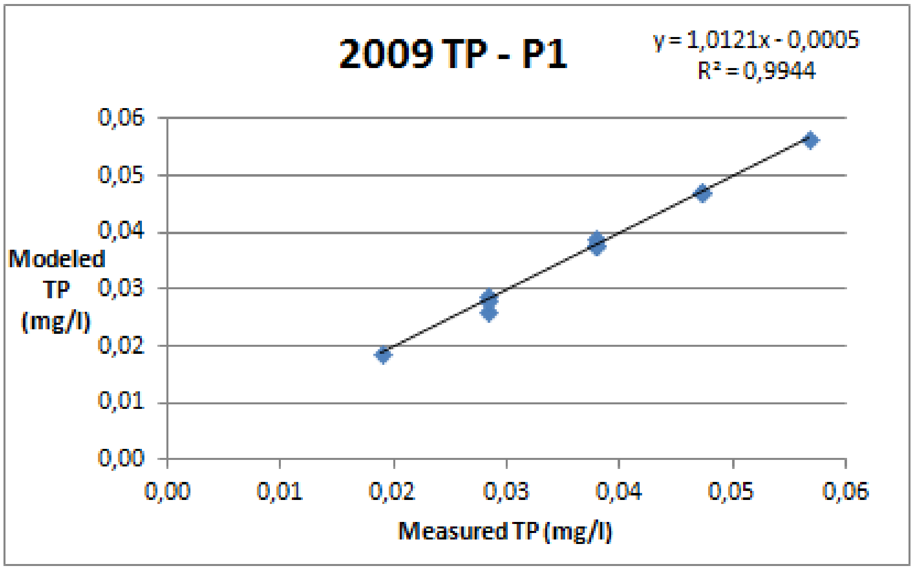


Figure 8.34. Correlation between TP modeled and measured data in 2009, in P1

The modeled data followed the measured data very closely (Figure 8.35).

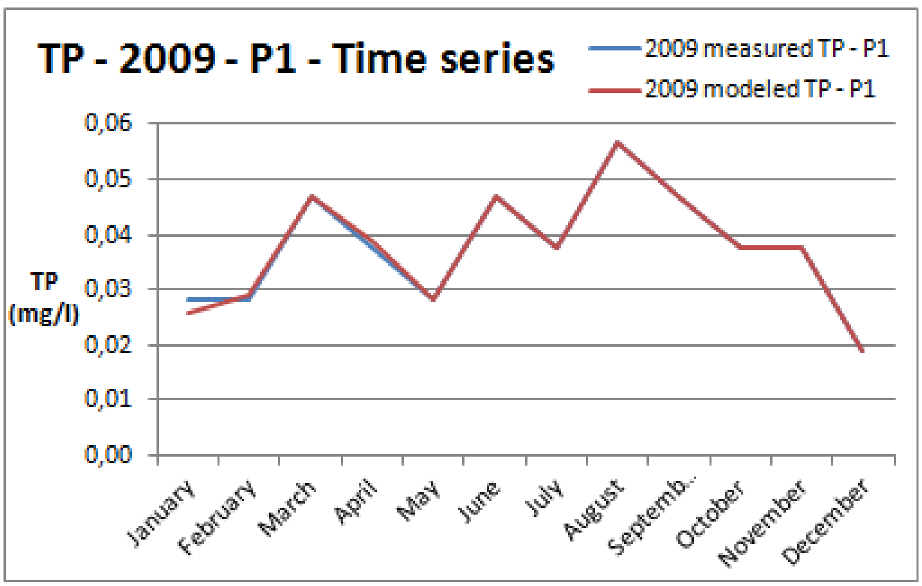


Figure 8.35. Time series for TP, for both measured and modeled data, in 2009, in P1

Very good results were found in P2 as well. The graph below (Figure 8.36) shows the TP data modeled and measured for 2009.

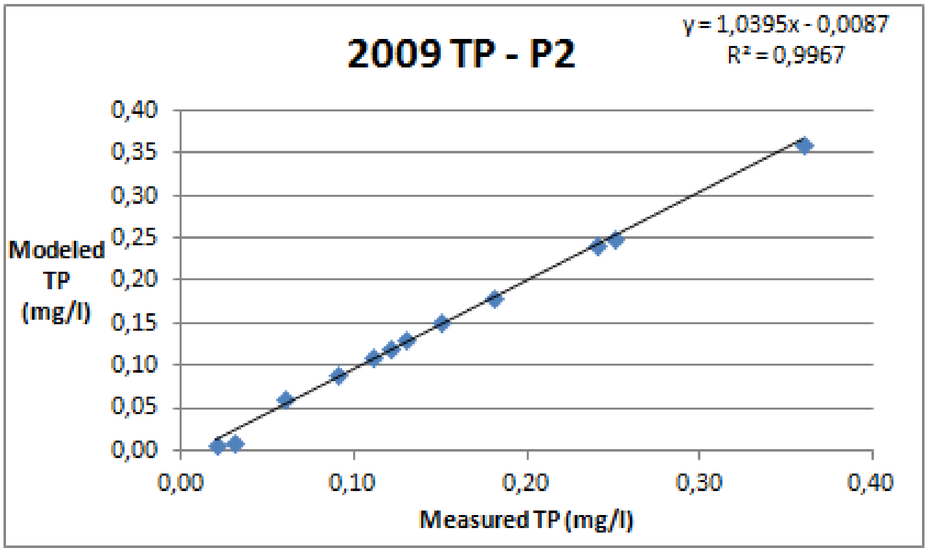


Figure 8.36. Correlation between TP modeled and measured data in 2009, in P2

In Figure 8.37 the time series for simulated and measured TP in 2009, in P2 show a very good match after bushfires followed by rain.

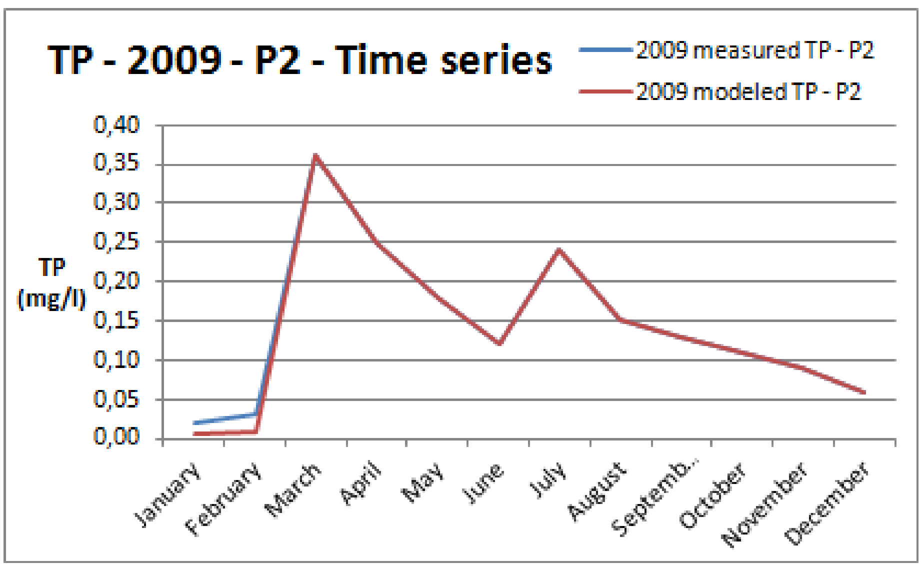


Figure 8.37. Time series for TP, for both measured and modeled data, in 2009, in P2

In Chapter 7.4.1 it was demonstrated the fact that the higher levels of TP in Latrobe catchment were recorded in P3. After introducing the coal mining landuse, the correlation coefficient increased from 0.9031 to 0.9965 (Figure 8.38).

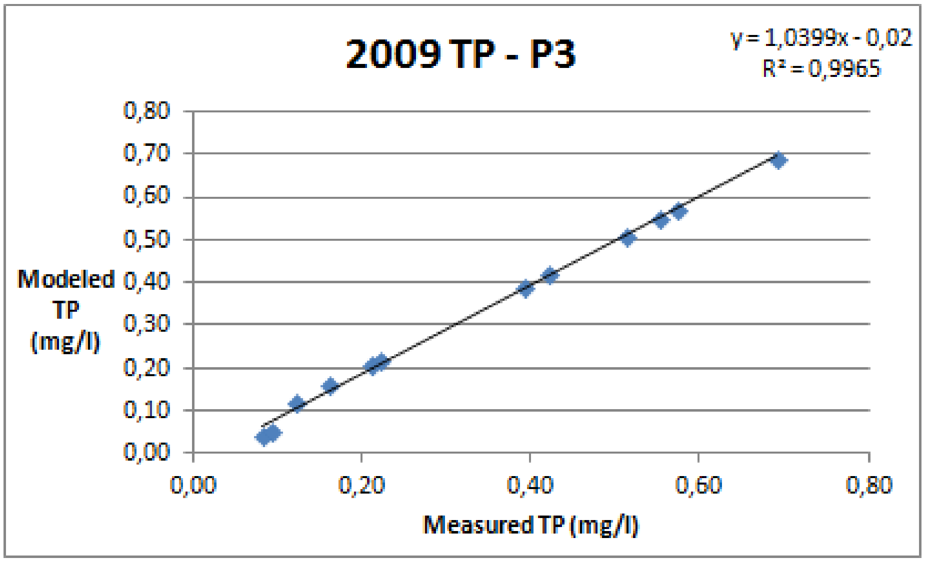


Figure 8.38. Correlation between TP modeled and measured data in 2009, in P3

The improvement is not related only to the increasing of the correlation coefficient, but also to the fact that the modeled values are very close by the measured data, so the model neither overestimates, nor underestimates. This is clearly displayed in Figure 8.39.

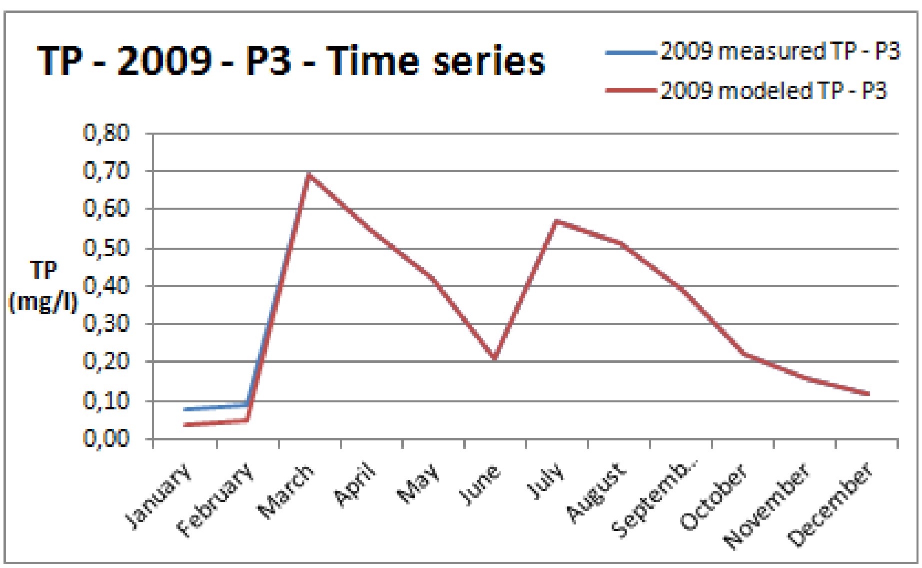


Figure 8.39. Time series for TP, for both measured and modeled data, in 2009, in P3

Another example which is displayed in Figure 8.40, is the correlation between the modeled and the mesured TN in 2009, in P4. The model predicted very well the TN pollution in this point, the correlation corfficient being very high (0.9956).

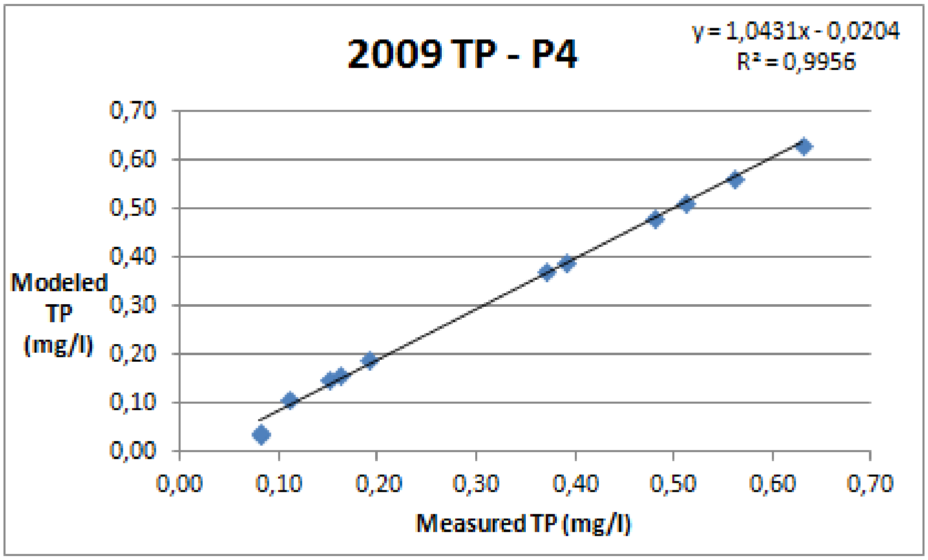


Figure 8.40. Correlation between TP modeled and measured data in 2009, in P4

In P4, the modeled data had the same behaviour as the measured data in 2009 after bushfires followed by rain, which is displayed in Figure 8.41.

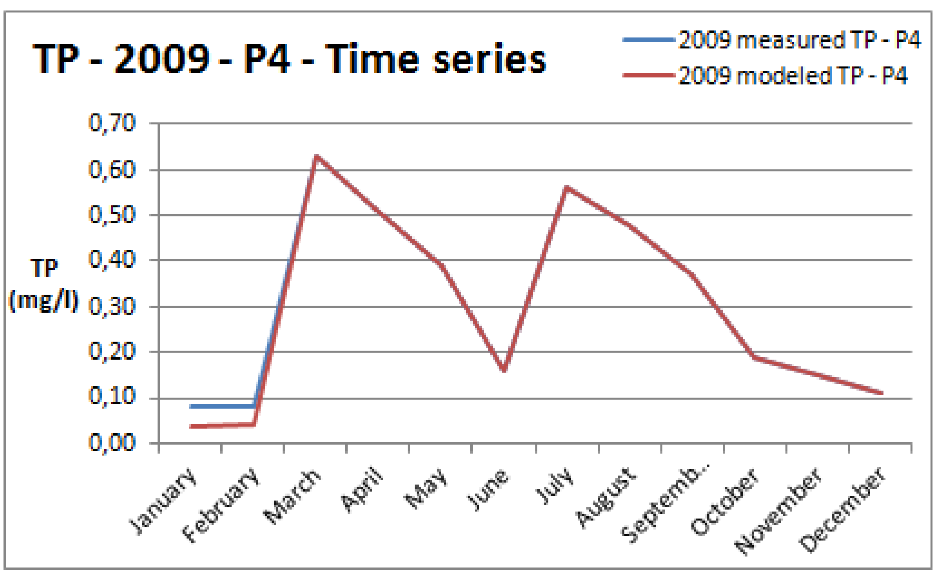


Figure 8.41. Time series for TP, for both measured and modeled data, in 2009, in P4

The chart displayed in Figure 8.42 shows a very good correlation between the modeled and the measured data, in 2009 in P5.

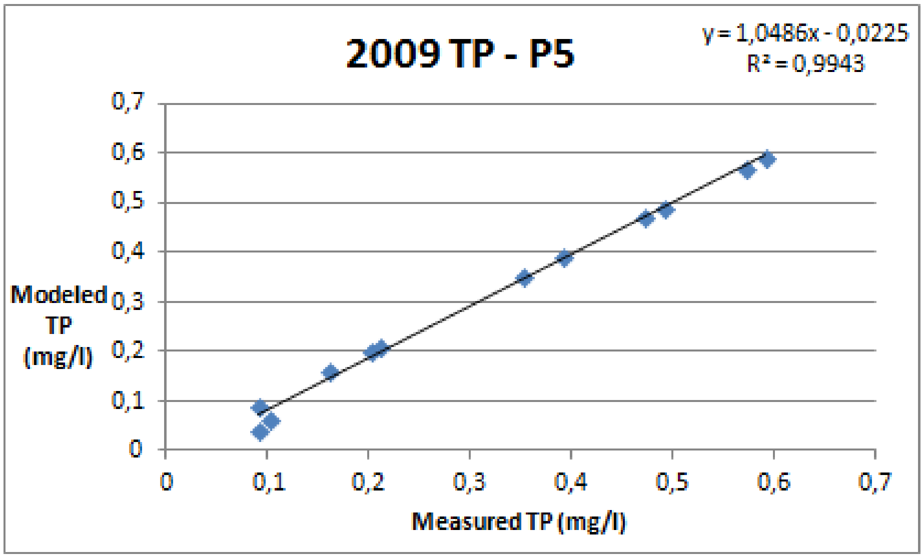


Figure 8.42. Correlation between TP modeled and measured data in 2009, in P5

In P5, the modeled data had the same behaviour as the measured data in 2009 after bushfires followed by rain, which is showed in Figure 8.43.

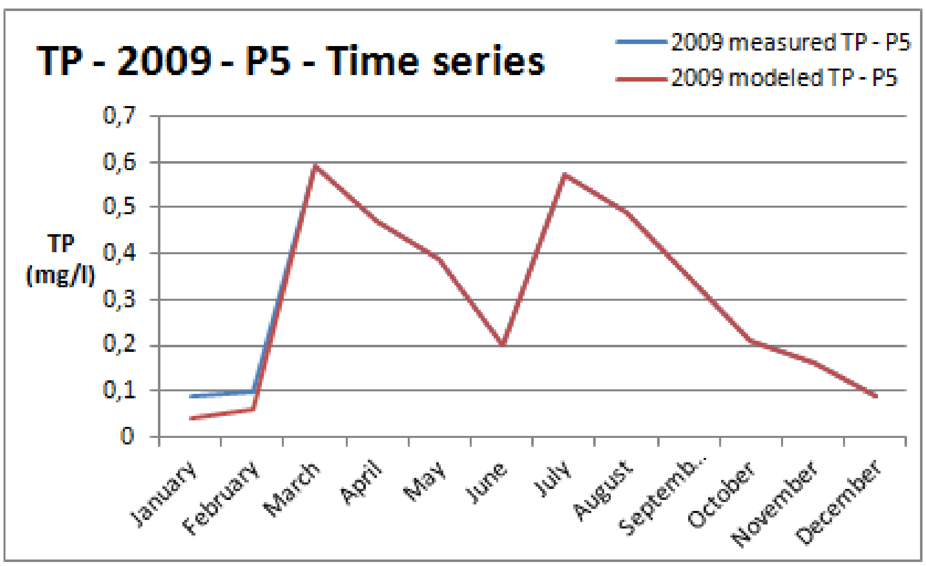


Figure 8.43. Time series for TP, for both measured and modeled data, in 2009, in P5

Another example which is displayed in Figure 8.44, is the correlation between the modeled and the mesured TN in 2009, in P6. The model predicted very well the TN pollution in this point, the value of the correlation coefficient being very high (0.9939).

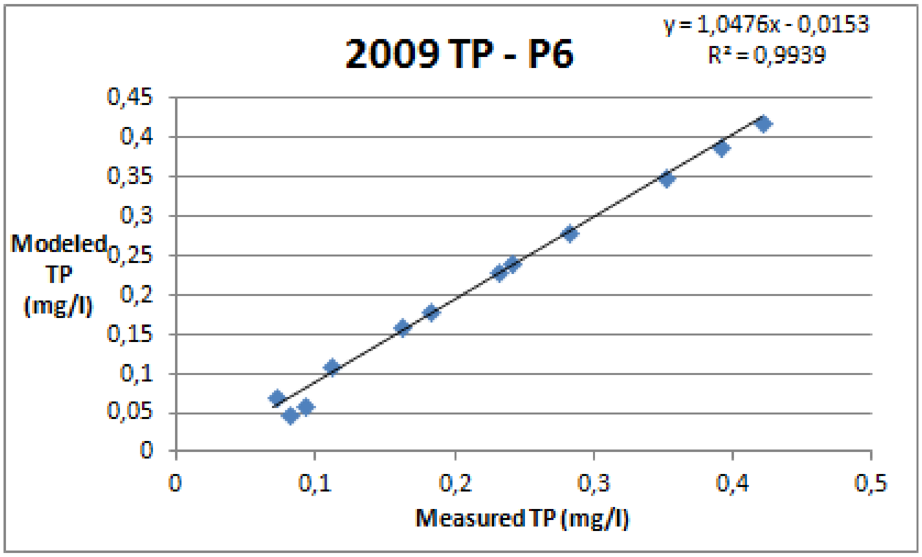


Figure 8.44. Correlation between TP modeled and measured data in 2009, in P6

In this point, the modeled data had the same behaviour as the measured data after bushfires followed by rain, which is displayed in Figure 8.45.

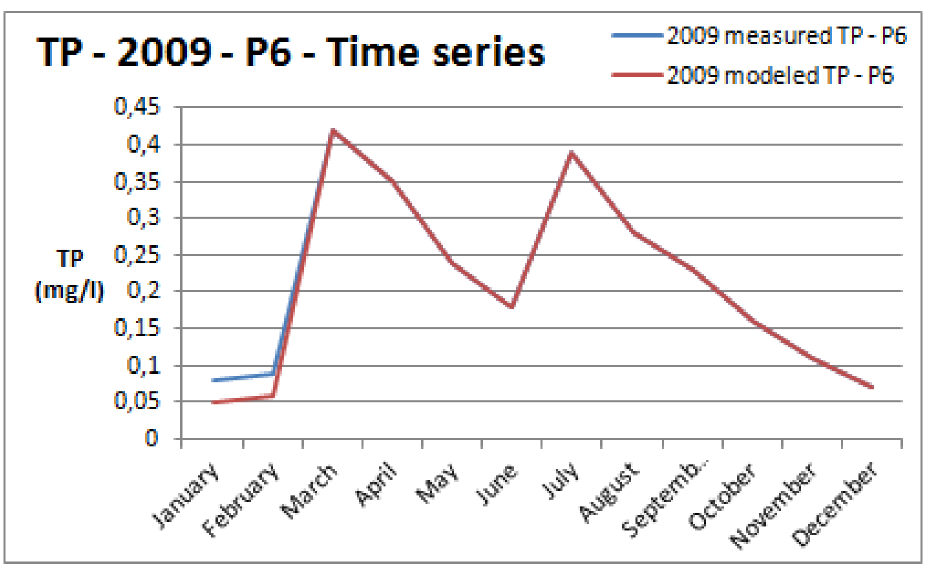


Figure 8.45. Time series for TP, for both measured and modeled data, in 2009, in P6

8.4. Conclusions

In this chapter, the parameterisation of the *eWater* model was improved by introducing the coal mining landuse. New values for the empirical parameters for rainfall runoff model and constituent generation model for this landuse were established. Also, the empirical parameters for the filter model were upgraded and they were applied for all types of landuse.

These empirical parameters were found using the measured TSS, TN and TP data recorded in Point 7 from Latrobe catchment. Then, the model was validated using the data recorded in Poins 1 to 6, within the catchment.

After this improvement the modeled values were very good correlated to the measured data, and followed almost the same trend in all points and for all period 2008-2016.

The modeled data in January and February, in 2009 are slightly smaller than the measured data. When the bushfires started in Latrobe catchment, it is likely that the wind transported small quantities of ash into the streams. The water pollution slightly increased, but the model was unable to consider this pollution. After bushfires followed by rain, the model is able to estimate with a very good accuracy the pollution in terms of TSS, TN and TP, in Latrobe catchment.

Introducing the coal mining landuse and changing the empirical parameters for the filter model, the model neither overestimates, nor underestimates the levels of TSS, TN and TP in the analysed area. The correlation coefficients between the modeled and the measured data (TSS, TP and TN) are very good, being higher than 0.9, which means that eWater is able to predict very well this pollution in the studied catchment. The correlations are even better in 2009, so the model is very suitable to be used after bushfires followed by rain, to help in the decision making process, for the catchment management.

9. CONCLUSIONS

9.1. Introduction

This chapter will recapitulate on the modeling approach developed to evaluate the impact of bushfires on water quality in catchments.
It will review the key highlights of what has been achieved and will conclude with the areas requiring further research.

9.2. The scope of the research

The aim of this research was to develop a spatial approach in order to predict the water quality parameters in rivers, especially after bushfires.
In Australia bushfires represent a natural phenomenon that occurs in summer, in dry conditions. They negatively impact the environment and the community.
After bushfires followed by rain, the ash and debris are transported into rivers, increasing the quantity of pollutants in water. Water quality monitoring is expensive and requires many resources. This leads to the necessity to find an option to predict water quality parameters, especially after bushfires, when their values become very high, and the quality of water is very poor.

9.3. Summary of research, model development and evaluation

To develop a research in the water quality field, an area had to be chosen. It had to be a bushfire prone area and it has previously had bushfires. There should have been enough data to complete the research; the area must have been big enough for reasonable modeling and, for more accurate results, the site needed to be mainly pristine.

This research developed a spatial approach that involved the implementation of a hydrological model in order to predict the river water quality, to assist in the decision-making process.

The model chosen for this research was *eWater* Source, developed by eWater CRC, Australia. The model is conceptual, semidistributed and applies the flow accumulation principles. There are rainfall runoff models, constituents generation models and filters models embedded in *eWater*, and they can be chosen depending on the aim of the project and the characteristics of the site. These models can be parameterised. The values of the empirical parameters were established after several tests. The model was run and the outputs were compared to the measured water quality data. The model was calibrated when a set of empirical parameters led to a good correlation between the modeled and the measured data for a specific point in the catchment. Then the model was validated using the other six points in the catchment, by using the sets of data recorded at these points.

The input data set is very important for the accuracy of the outputs. The model required elevation, fire and meteorological data, landuse and water flow. The model was implemented for 18 types of landuse, obtained by combining the fire and rain intensity with the vegetation general characteristics. A good set of parameters was found (Chapter 7).

The correlation coefficients for the modeled and the measured data were between 0.786 and 0.9631 in all simulated points in the catchments and for the entire period of the research.

Point 1 had low values of TSS, TN and TP, being situated upstream of the burnt areas, so the bushfires did not affect this point. Figure 8.1, in Chapter 8.2 shows the location for all of the points in relation to the burnt areas.

The highest TSS values in 2009 were predicted at P5, and then in P6 the pollution was diluted, in perfect accord with the measured data, as it was displayed in Figure 7.34. The highest levels of TN and TP were predicted at P3, as the measured data showed, then the pollution slowly decreased, the smallest values being modeled at P6. The TN values were plotted in Figure 7.62 and the TP concentrations were shown in Figure 7.77.

Analysing over the research period, it showed that TSS values were higher in 2009, when the bushfires occurred in the Latrobe catchment, then in 2010 the level decreased, and then in 2011 the level became normal. Therefore after 2009 it only took one year for TSS to return to normal.

For the TN values, the highest levels were predicted in 2009, as it was expected, then the TN levels gradually decreased until 2011. Then since 2012, the TN values became normal and so the TN pollution persisted 2 years more after 2009.

The highest TP levels were recorded in 2009, when the bushfires were in the catchment, and the TP values became smaller every year until 2014, when the TP levels became normal. Therefore the high levels of TP persisted in Latrobe catchment 4 more years after the bushfires.

The modeled data followed the same trend of the measured data. However the model overestimated, and so it was able to reasonably predict the water quality parameters established (TSS, TN and TP). These results were discussed in Chapter 7.

The water quality predicted by the model could be considered a worse case scenario. However taking actions in this case could mean wasting more resources than necessary. So, improving the model performance was necessary.

At this stage coal mining was taken into account as another landuse and some empirical parameters were changed. The results have been greatly improved: the correlation coefficients were greater than 0.9025 and the modeled data values were very close to the measured data. This was also true after the bushfires followed by rain in all simulated points in the catchment and for the whole study period. This means that the model is able to predict very well the water quality parameters (TSS, TN and TP at this stage) in the catchment. These improved results were discussed in Chapter 8.

9.4. Did the study answer the research questions?

The aim of this research project was to develop a spatial approach, to support the planning of the water quality in the areas subjected to bushfires. This was discussed in Chapter 1. In order to meet this objective, it was necessary to answer the following research questions, which were set in the first chapter.

9.4.1. What information is required to establish the water quality and what are the gaps in existing local water quality databases?

To avoid deploying monitoring campaigns, the modeling tools can be applied in order to predict the water quality in a catchment. This requires a specific set of data as input which consists of elevation, fire and meteorological data, landuse and water flow. Also, for the model calibration and validation, sets of water quality data are required. The water quality data is available on the Department of Environment, Land, Water and Planning website.

The data is recorded one time every month. For a period of about 29-30 days, between two moments when the data is collected, the water quality parameters could get any value. In such a long period, the concentrations can reach very high values, sometimes very dangerous for the population. These peaks are not currently recorded. The authorities are not able to advise people of the danger, and prevention programs cannot be developed.

There are many monitoring points which are no longer in operation) and also many sets of data with errors (found in Chapter 7). These could not be used in this research.

9.4.2. Which pollutants are affected by fire and by how much?

The chemicals created after bushfires are transported in streams and rivers. The ash which resulted after the burnt vegetation contains heavy metals, nutrients such as nitrogen and phosphorus, and many other chemicals depending on the landuse. Also, the runoff increases after bushfire and important quantities of debris is carried into streams. Some of the water quality parameters increase after bushfire between two and six times (Chapter 3 Part1).

9.4.3. How can a hydrological model be used to integrate datasets, to provide missing information in existing water quality database?

Using a hydrological model is a better option to replace the water quality monitoring campaigns which are very expensive and time consuming and requires many resources in terms of people and equipment.

To be able to successfully predict the water quality parameters, a model requires a set of reliable input data and water quality data for calibration and validation. The model has been calibrated and validated for a specific catchment, and therefore the model is able to provide the water quality parameters for any other periods of time for that catchment, so it is able to create a reliable derived water quality database. Also, following the steps for calibrating and validating the model, realistic parameters can be determined in other catchments.

9.4.4. How can we predict future impacts?

Running eWater model calibrated and validated for a specific catchment, the water quality parameters can be predicted for any periods of time, using suitable input data. Even when the bushfires are predicted, but they have not occurred yet, the impact of those possible bushfires can be estimated using the available meteorological and hydrological data from previous years, and used for the same period of the year. Thus, the possible negative effects of bushfires can be known by the authorities and countered.

9.5. Limitations of the research findings

The main limitations of this research are related to the accuracy of measured data. The input data including the DEM (Digital Elevation Model), landuse, river water flow, fires data, and meteorological data (rain and evapotranspiration) which are used for the model validation have their measurement uncertainty.

Using the input data, the model provided water quality parameters. To validate the model, the modeled water quality parameters are compared to the measured data. Once the model is validated, it can be used in the catchment for any other period of time.

In this research, the modeled monthly value of the pollutant was calculated using the modeled daily data. Then, the values were compared to the measured values, which were monthly data. The measured values were not averages of daily data. This might decrease the accuracy of the results. A set of measured daily water quality data (if available), would lead to determine the empirical parameters of the model with higher precision, then the model would be able to predict the water quality parameters with better accuracy.

Also, the 25 metres DEM was created from the 5 metre elevation data, available on the Geosciences Australia website. A better resolution of the DEM (after filling the sinks) would improve the accuracy of the elevation data. These data will be able to take into account smaller rain flows that could appear in the study area. These could carry pollutants in the stream. There could be tens or hundreds of small flows like this, and the computed quantities could be very high, as well as the quantities of pollutants carried in the stream. All these quantities cannot be measured using a 25 m DEM. Using a DEM with a better resolution will definitely improve the accuracy of the outputs.

9.6. The generalisation of the research findings

The model used was parameterised for a specific site and it is able to predict the river pollution in terms of TSS (Total Suspended Solids), TN (Total Nitrogen) and TP (Total Phosphorus) with high accuracy. Following the same steps, the values of the empirical parameters established for Latrobe catchments can be modified to be suitable for any other catchment. In this way, the monitoring campaigns which are very expensive and time/resources consuming can be successfully replaced.

9.7. Contributions to water management research

The contributions from this research can be summarised as follows:

9.7.1. The relevant agencies in water management, in Australia

Being aware of the water quality parameters in a catchment, the relevant water management agencies can be more efficient, especially after bushfires that are followed by rain.

In this research the roles and responsibilities of relevant agencies in water management were considered. The whole process related to the water quality management is based on national guidelines that are implemented at State, regional and local levels. The Federal Government through The Department of the Environment and Energy (DEE) designs and implements the Australian Government's policies and programs to protect and conserve the water.

The Victorian Government, at the state level, uses water quality planning and policy instrument, taking into account the national goals and obligations to other States and Territories.

Local governments are the responsible authorities for water quality planning and they establish the strategic directions for the protection of water, as a resource.

9.7.2. Creating a landuse database suitable for eWater modeling

The landuse database was necessary to run the hydrological model. It was created using a combination between the fire intensity, the rain intensity and the vegetation type. The database consists of 18 types of landuse (in Chapter 7) and then a new landuse (coal mining) was added (Chapter 8).

9.7.3. Developing a spatial approach in order to predict the water quality

In this thesis the parameterisation of a hydrological model was done, in order to successfully predict the water quality parameters in the catchment. The best set of empirical parameters was found after several tests, followed by the comparison between the modeled and the measured data. The model was able to reasonably predict the TSS, TN and TP concentrations in Latrobe catchment for the entire research period. It should be noted that it overestimated in all cases.

9.7.4. Improving the accuracy of the model applied

Introducing a new landuse (the coal mining), the accuracy of the model outputs has improved considerably. At this stage, the model is able to successfully predic the water quality parameters in all simulating points in the Latrobe catchment, for any period of time. The resulting correlation coefficient were higher than 0.9.

9.8. Importance of this research

The Australian Bureau of Meteorology has notified rainfall deficiencies (Bureau of Meteorology, 2017a) and the recorded data showed that Australia has warmed by approximately one degree since 1910. The warming has occurred mostly since 1950 (Bureau of Meteorology, 2017b). The rainfall deficiencies and high temperatures lead to an increase in the number and severity of bushfires and negatively impact on water resources.

Also, the population living in all states and territories from Australia has increased since 2011 (Australian Bureau of Statistics, 2017a) and it is expected to continue to increase according to the Australian Bureau of Statistics (Australian Bureau of Statistics, 2017b). This will definitely lead to an increase in water demand, and the quality of water is highly important.

The approach established in this thesis can be successfully applied in burnt areas and also in areas which are not affected by bushfires.

9.9. Further research and recommendations

At this stage, the model can be successfully applied in the Latrobe catchment for any periods of time, to predict the water quality parameters such as TSS (Total Suspended Solids), TN (Total Nitrogen) and TP (Total Phosphorus).

As a future research, the model can be applied to predict water quality parameters such as pH, heavy metals and pesticides. For every chemical component, following the same steps explained in this thesis, the empirical parameters can be established, making a comparison of the modeled data with the measured data. However, a reliable database of the water quality parameters must be available.

Also, the work can be extended to another catchment. Following the same steps, the empirical parameters associated to a new catchment can be determined and the model can be applied in the selected catchment.

Taking into account the importance of this research and the limitations of the research findings, extensive monitoring campaigns are recommended. Daily measurements of the water quality parameters lead to a better accuracy of the measured data which is compared to the modeled data. In this way, the empirical parameters of the hydrological model can be highly improved. The number of monitoring points depends on various parameters such as landuse, type of soil, size and surface of the area of interest. The monitoring points must be located where the levels of pollution might be higher (where the rain transports the debris into river), and especially in the bushfire prone areas.

9.10. Conclusions

This chapter is a brief revision of the research undertaken in this project.

The scope of the research, the steps followed in model development and evaluation, and the results obtained were highlighted.

Also, the research questions have been discussed and limitations were considered.

A generalisation of the research findings was made, personal contributions were listed.

Finally, the importance of this research was highlighted and recommendations for future research were discussed.

Whilst this thesis has demonstrated how modelling can be used to assess the quality of water after a bushfire has affected a catchment, managers can now use the results from this modelling to identify areas for rehabilitation. The modelling also allows managers to ascertain the overall impact from bushfire on catchments they manage.

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