A Fight for Flow - Conservation, Preservation and Management of Groundwater Dependent Ecosystems, Berry Springs, Northern Territory, Australia.

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For Macquarie University and Northern Territory Government
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L. Williams, 41601165
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1. Abstract

The aim of this paper is to investigate the Groundwater Dependent Ecosystems (GDE's) in the Berry Springs region in the Darwin Rural area of the Northern Territory.

There has been very little research undertaken on GDE requirements in Berry Springs. The following research and field work aims to document;

- Collect, analyse available data to determine Environmental flow requirements required to maintain ecosystem health;
- Explore impacts of current land use of the Berry Springs Dolomite Aquifer;
- Assist in providing understanding and insight in the scientific and management issues facing Berry Springs for 2010 water allocation planning processes.

The Berry Springs region will be subject to Water Allocation Planning in 2010 by the Northern Territory Government to meet National Water Initiatives. This project will provide information to assist in the planning process by defining the requirements for GDE survival in the Berry Springs area.

2. Introduction

2.1 Groundwater Dependent Ecosystems (GDE)

The term Groundwater Dependent Ecosystems encompasses ecosystems that use or depend on groundwater for survival and this can range from partial reliance to complete reliance on Groundwater, generally during periods of little or no rainfall.

Surface water flows and rainfall runoff also play an integral role in GDE's in the North of Australia which rely upon the recharge of groundwater storages through infiltration, paleorecharge and parafluvial exchange in river and creek beds. Within Australia, there are a plethora of GDE's and their biota that rely on surface water recharge and groundwater discharge to maintain healthy and functioning ecosystems, the dependency of GDE are described in Table 2-1 .

GDE Classification	Groundwater Dependency
Terrestrial Vegetation and Fauna	Rely upon shallow groundwater tables to sustain transpiration and growth through dry periods and access to surface water for drinking.
Wetlands	Those that are seasonally waterlogged or flooded depend on high groundwater levels to sustain a level of inundation.
River Baseflow Systems (RBS)	Stream flows during the dry indicate Groundwater stream flows, which are vital to the composition of in-stream and near stream ecosystems.
Aquifer and Cave Systems	Scientifically, little is known about the biota o these systems however subterranean life exists in different types of karstic cave, porous and fissured aquifers.
Estuarine and Nearshore Marine Systems	Are counterparts of the terrestrial ecosystems and include coastal mangroves and salt marshes, coastal lakes, sea grass beds and marine animals. Some marine and estuarine animals depend on groundwater discharge to assist them in regulating salt intake within their cells through osmosis by diluting salinity in seawater and/or providing access to freshwater.

Table 2-1 Description of GDE Types

Recharge of an aquifer can vary between geographical region, rock type and the location of an aquifer within a catchment. It can take years or decades for groundwater systems to adjust to the input/output equilibrium water levels (DNRETA, 2007). The term groundwater mining is used when extraction exceeds the rate of recharge. The time residence of groundwater systems can make it a non renewable resource considering the short term effects of rate and volume of extraction in relation to time taken for recharge. Older groundwater systems with a residence time of 10, 000 years; paleorecharge may have been much greater than what occurs today and estimation of current sustainable extraction rates may be trial and error (DNRETA, 2007).

The functional dependency of river base flow systems (RBS) and their ecosystems on the additive effects of groundwater contributions from springs, seeps, hyporrheic zones and parafluvial zones has never been assessed at the catchment scale in Australia (Boulton, 2006). In the north there has been even less research undertaken on tropical GDE's and the changes of in-flow regimes through changes in surrounding land use. Therefore the role of baseflow mesohabitat heterogeneity in groundwater- dominated rivers, even during dry periods, is a subtle yet critical aspect of dependency in RBS and requires further investigation, particularly when determining environmental flow allocations (SKM, 2001).

2.2 Classifying Groundwater Dependent Ecosystems

In broad terms, 5 categories of groundwater dependency for Berry Springs dolomite aquifer of which include:

a) Riparian vegetation
b) Wetlands (vegetation and faunal)
c) Riverine dry season base-flow systems (mainly faunal)
d) Terrestrial fauna
e) Terrestrial vegetation

Berry Creek relies upon spring discharge to maintain in-stream and stream bank vegetation, is a popular recreational swimming area for locals and tourists, and permanent waterhole for fauna in the region. It is a place of cultural significance for local Indigenous groups. Increasing changes in climate and seasonal weather patterns and increasing demands on groundwater and surface water use for domestic, horticultural and industry have placed pressure on groundwater reserves.

The level of groundwater dependency of GDEs varies within categories depending on relative position in the broader landscape. Different stands of terrestrial vegetation, fauna and aquatic biota although requiring seasonal access to groundwater (Murray et al., 2003) may vary significantly in their level of dependence. In fact classification systems developed by the Natural Heritage Trust through the National River Health Program identify in relation to the integrity of level and water quality attributes of karstic groundwater ecosystems that vulnerability to human induced impacts, the realisation of such risks and conservation values are considered high (SKM, 2001)

Therefore flux and quality is crucial to integrity of the Berry Springs Dolomite Aquifer and in surface expression either as springs, soaks, swamps, wetlands and dry season flow in Berry Creek from the Berry Springs.

Environmental Water Requirements (EWR) of GDE's can be defined as the water requirements needed to sustain its key ecological values. It is vital that EWR's are understood to ensure suitable management of groundwater resources consistent with principles of ecologically sustainable development.

Environmental water requirements are determined through an understanding of 4 key factors:

1) The nature of ecosystem dependency on groundwater input;
2) Water requirements of the ecosystem;
3) Groundwater regime, satisfactory in supplying the water requirements of the ecosystem; and
4) The impacts of changes in groundwater regime on ecological processes.

SKM (2001) considers that there are few studies in Australia where the environmental water requirements of GDE's have been determined through direct field research. This study will endeavour to provide a basis for discussion in determining EWR's for the Berry Springs Dolomite Aquifer (and associated springs) in response to upcoming water allocation planning in 2010.

The interaction of groundwater and surface water systems can be directly observed in particular catchments and settings. A field reconnaissance survey can be useful in the initial stages of an assessment to identify specific locations that warrant further investigation and assist in selecting appropriate monitoring and sampling sites. A survey of this nature can also be fruitful in providing guidance to the parameters that could be measured to help quantify connectivity and also to identify the management issues impacted by the connectivity.

Winter et al (1998) states that there are a range of field indicators of direct groundwater discharge into streams, lakes or estuaries including:

- the direct observation of water flow from seepages and springs at the margins or within the bed of the surface water feature. Underwater discharge of groundwater can be observed if the flow rates are sufficiently high

- in colder times of the year, the water vapour above discharge zones may be observed due to the contrast between the groundwater and air temperatures. Likewise, in alpine areas during winter, seepage areas can remain continually ice or snow-free in contrast with their surroundings;

- changes in the groundwater chemistry due to mixing with surface water can result in mineral precipitates such as iron and manganese oxides. These commonly form with the contact of anoxic groundwater with oxygenated surface water. Iron bacteria that oxidise the dissolved ferrous form ($Fe2+$) to the ferric form ($Fe3+$) can also occur as filaments and accumulations. This can be accompanied by an oily sheen on the water surface, similar in appearance to a petrol film.

- carbonate precipitates such as tufa or travertine deposits can indicate discharge of groundwater with high levels of dissolved carbon dioxide and calcium carbonate, notably in a karst landscape. These can form spectacular terraces, cascades and dams that can significantly modify stream morphology. Precipitation commences downstream of where groundwater discharge occurs, when degassing of carbon dioxide leads to supersaturated conditions in the surface water with respect to calcite. Stream reaches with abrupt changes in gradient tend to be preferred sites of deposition because turbulent stream flow can enhance carbon dioxide outgassing and;

- water colour and odour can be an indicator, particularly if the groundwater is contaminated. This may be the case in catchments with urban, industrial, mining or intensive agricultural development. Discharge of highly acidic groundwater can be indicated by a dramatic increase in the clarity of the surface water, due to the flocculating of clay particles by elevated levels of dissolved aluminium.

A survey can also help determine the scope and development of monitoring programs in achieving desired outcomes for the study through an understanding of a number of site related issue such as parameter suitability, equipment requirements, access and safety requirements. The methodologies adopted in this study are described in greater detail in Section 3.

2.3 Groundwater Extraction and Land Use Impact

Similar to many other ecosystems, GDE's face a plethora of direct and indirect anthropogenic threats. Threats may impact on the ecosystem directly and/or on the hydrologic processes in which they depend on. Activities that occur during the development of such land uses can also increase the severity of the impact on an ecosystem. The major threatening process to GDEs in the North of Australia includes the following.

Agricultural Land Use

Intensive agricultural land use is associated with changes in vegetation cover and recharge/discharge relationships within catchments. The extent of the impact of changes varies with the physical characteristics of a landscape such as climate, soils, topography, geomorphology and hydrogeology, the level of change in native vegetation and the management of agricultural land. Issues associated with dry land agriculture such as rises in groundwater tables and salinity have directly and indirectly through stream channels and salt wash-off contributed to increased salinity in tributary streams and major rivers. Irrigated agriculture is also having similar impacts on landscapes and continuously high water tables in wetlands and, as a consequence, can cause a change in the water regime that may not suit species and prevent periodic drying essential to ecological processes of some wetland environments. Application of chemicals and herbicides can also affect water quality within groundwater and surface water systems through infiltration and runoff. Contamination of such environments can lead to imbalances in biota and in-stream quality assisting in algal blooms or accumulate through the food chain posing a threat to higher predatory animals such as birds, mammals and marine organisms. Drainage of agricultural land in coastal regions may activate acid-sulphate soils and severely impact on stream, estuary and nearshore marine environments.

Urban and Industrial Development

Urban and industrial developments have the potential to influence hydrological attributes that govern ecosystem function and through associated activities such as clearing, drainage and land reclamation displace ecosystems. Development associated with intensification of groundwater use will result in the reduction of groundwater levels. If bore fields are located in close proximity to GDE's it could have a direct effect on groundwater flows into the GDE. Drainage development and construction of marinas will have an effect on groundwater recharge in dependent wetland, terrestrial and riparian vegetation. Discharge from septic tanks, use of herbicides and pesticides, industrial chemical spills, and garbage dumps may all contribute to point source pollution through infiltration, runoff or direct contamination, possibly resulting in changes in chemical parameters of ecosystems and contributing to algal blooms or intoxification of organisms.

Water Resource Development

The consumptive use of freshwater resources, particularly groundwater, pose major implications for GDE's in relation to ecological processes both nationally and internationally. In Northern Australia, surface water consumptive use must also be carefully considered when determining surface water allocation for GDE's as many rely on wet season flows and or contribution of surface water (billabongs and wetlands) for recharge through the parafluvial zone and hyporrheic zone (Boulton, 2006). Increased abstraction can lead to a reduction in river base flows during the dry season and access to water for fauna and a reduction in water table levels where vegetation is dependent on.

2.4 Tools for Identifying and Assessing Data Deficient GDE's in Northern Australia

By placing an economic value to a natural resource, planners and government bodies are able to quantifiably justify the protection and management of ecosystems. Often in most cases values are determined by the needs and want of stakeholders groups utilising the resource and directly relate to their level of dependency on the resource. Environmental and cultural values of GDE's and ecosystems in general are often neglected by stakeholders and the overall ecosystem health and process poorly understood.

A method for identifying and evaluating current or perceived impacts on GDE's from surrounding land use could assist in prioritising and categorising research and policy development at a local and regional scale. An assessment such as the one presented in Table 3 below highlight the perceived impacts on Berry Springs by surrounding land use. Understanding the perceived impacts may assist Water Allocation Planners and Scientists to determine areas that may need more research and gaps in data before planning decisions are made. Predicting perceived impacts is also a useful educational tool in informing those who hold values to the GDE, wether positively or negatively impacting on the resources on the problematic issues that may affect them with the loss of the GDE. Table 2- Activities Associated with Land Use lists some of the activities associated with threats to ecosystems and Table 3- Impacts of Land Use Types represents the perceived impacts of Land Uses upon Berry Springs and its associated system.

Impacts	Symbol
Clearing - Clearing of all native vegetation - Clearing of mid story - Clearing of understorey	CL
Erosion and Sedimentation	ES
Chemical Use - pesticides and herbicides - Petrochemicals	CU
Fire Regime Changes	F
Hydrological Change - Changed runoff - Infiltration into Groundwater - Dryland salinity - Changed flow regimes - Constructed dams and channels - Fish barriers - Rise in Groundwater table - Over extraction (surface water and groundwater) - Wet season harvesting and off stream storage	H
Nutrient Source and Loads - Diffuse nutrient sources - Increased basin nutrient loads - Point nutrient sources - sewerage	NSL
Feral Animals and Weeds	FAW
Climate Variability - Rainfall patterns - Temperature - Potential impacts of climate change - Natural phenomenon's such as flood and cyclone	CV
Loss in Biodiversity of Flora and Fauna - Displacement of biota - Changes in ecosystem function - Loss and Extinction of species - Loss of habitat	B
Cultural and Social Impacts - Displacement of cultural rights - Restriction to access - Health implications - Sacred sites and cultural beliefs	C

Table 2-2 Threatening Impacts Associated with Land Use

It is evident that through a quick assessment of land use and associated impacts that all land use types have some impact on the GDE despite initial appearance or intention (Such as the nature Reserve) to preserve ecological health, process and function. Further investigation would have to be undertaken to assess the extent and proximity of varying land uses to the GDE as well as a review of extraction rates.

Land Use	Perceived Impacts on GDE's	Location within Catchment
Berry Springs Nature Reserve (Recreational Swimming Area)	F, C, FAW, CL, ES, NSL, B	Lower catchment
Berry Springs School/ Sports Reserve	CL, ES, H, NSL, FAW, B,	Lower Catchment
Commercial Agriculture	ES, FAW, B, CL, CU, H	Upper and Lower Catchment
Subsistence Farming/Market Farms	ES, FAW, B, CL, CU, H	Upper and Lower Catchment
Bottle Water Industry	H	Upper Catchment
Caravan Park/Resort	NSL, ES, CU, H, FAW, B, CL	Upper and Lower Catchment
Territory Wildlife Park	ES, H, NSL, B, CL, F	Upper and Lower Catchment
Domestic Users	H, NSL, B, CL, ES, FAW, B	Upper and Lower Catchment

Table 2-3 Impacts of Land Use on Berry Springs

Also understanding the water requirements and water demand by all stakeholder groups will assist Planners in making more informed decisions during the allocation process. Groundwater and surface water modelling are tools that assist with scenario modelling and can be used to assess the short and long term effects of land use impact and over extraction if the appropriate scientific data (current and historical data) has been collected. Other informal methods such as a photo library and anecdotal evidence from locals and informal studies may also assist Planners in understanding the trends and changes in water use, climate variability and demand in the region.

The Australian Catchment, River and Estuary Assessment (ACREA) 2002 also provides an assessment tool in which gauge the aggregate impacts of natural resource use on catchment, river and estuary condition and identify priority management challenges for the maintenance of GDE's on a regional scale. This process encompasses four major components of management. All components address both ecosystem condition and ecosystem processes for each environment. Health considers the status of the whole system rather than individual components. Ecosystem condition drivers include biophysical elements and processes as well as socioeconomic factors such as market prices, profitability and aesthetic, recreational and cultural values (SKM, 2001).

3. Berry Springs – A Case Study of GDE in Northern Australia

Berry Springs is located 47km south of Darwin and is a popular with locals. More importantly the springs provide for the existence of environmental and cultural values unique to the region by the existence of access to water all year round.

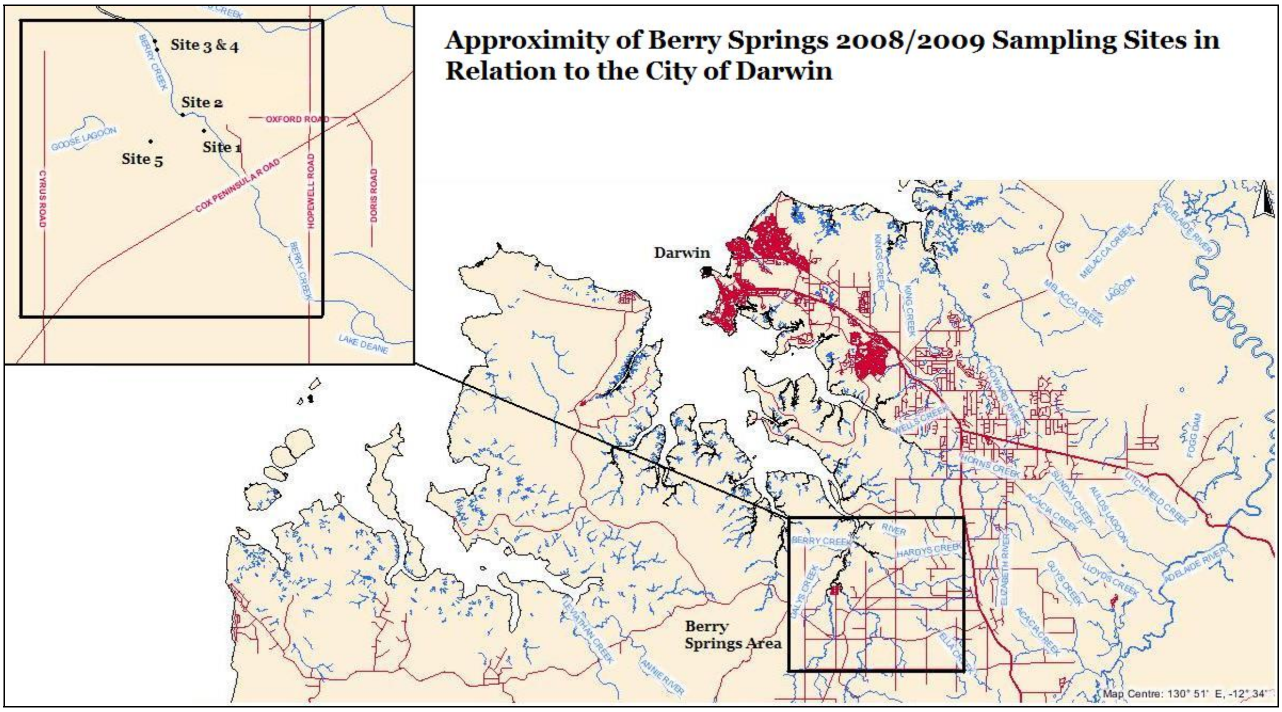


Figure 3-1 ***Location of Study Sampling Sites in Relation to Darwin, NT***

Berry Springs is an outer suburban bush area in the Greater Darwin Region. The name "Berry Springs" derived from "Berry Creek", named by Goyder in 1870, after his Chief Draftsman, Edwin S Berry. During World War Two Berry Springs was part of a rest and recreational camp set up by the armed forces for 100,000 personnel based in the area. A number of structures such as a weir (still present today) were constructed during this time.

It is a suburban bush area comprised of a mixture of varying sized estates offering bush-style living to Darwin residents in close proximity to the city of Darwin. There are also a number of varying land uses within the region that rely on ground wand surface water to function, of which include:

- Rural Living (house blocks);
- Small to medium scaled market garden farms (mangoes, Asian vegetables and livestock);
- Large scaled horticulture (orchids, mangoes, Asian vegetables);
- Medium sized agricultural Farms (cattle);
- Large aquaculture farms (barramundi, crabs & prawns);
- Light commercial industry such as caravan parks, shops, petrol station and hardware store;
- Community facilities such as schools and recreational ovals;
- Tourism enterprises such as the Territory Wildlife Park; and
- Designated Parks and Reserves such as berry Springs Nature Reserve.

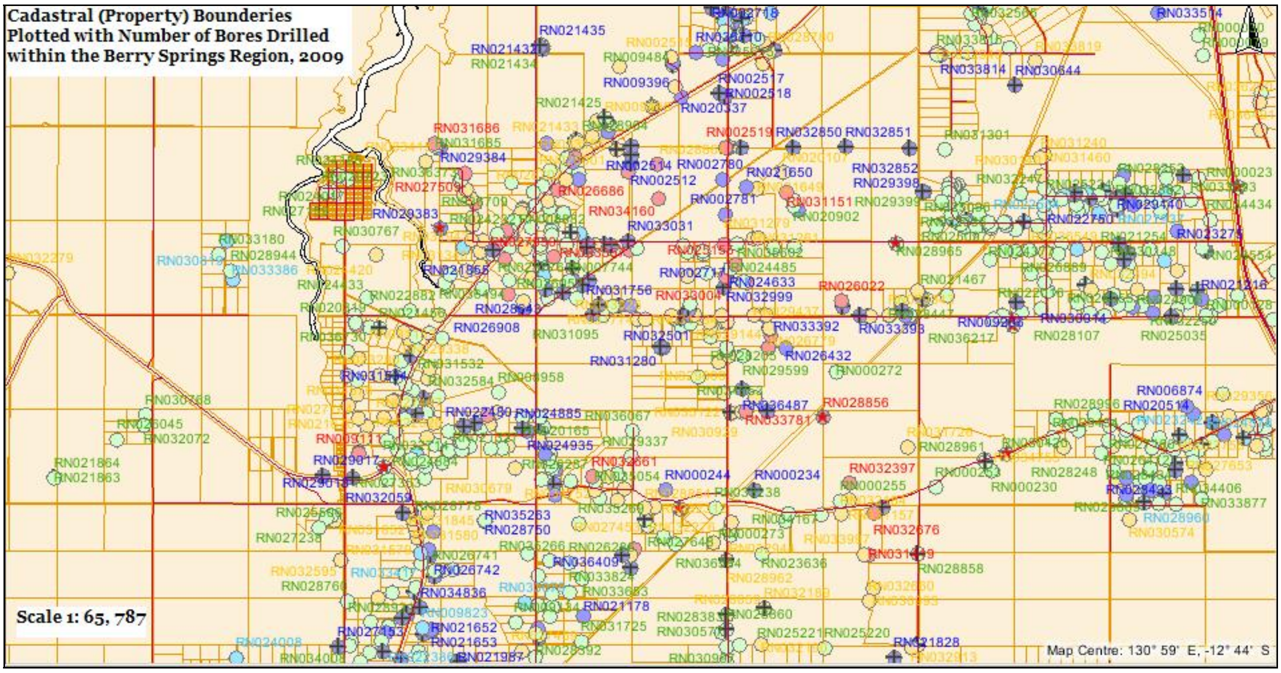


Figure 3 -2 Cadastral Boundaries and Number of Bores Drilled within the Berry Springs Region, 2009

Of these land-uses many vary in water demand and consumption. For example mango, Asian vegetables and aquaculture developments demand higher water requirements, particularly throughout drier periods of the year where little or no rainfall is received and constant irrigation is required.

The water which seeps into the ground in the Top End is naturally acidic and is corrosive to dolomite. Over time, the dolomite has gradually dissolved leaving a sponge like rock capable of holding large amounts of water, forming the localised aquifer known as the Berry Springs Dolomite Aquifer (DNRETA, 2007). The springs itself consists of numerous individual springs that spread along both the main fault and smaller ones, all of which are interconnected (DNRETA, 2007). Due to high yields and perceptions of 'plenty of water' by the community within this aquifer, the suburb of Berry Springs has in the past been seen as an ideal area for medium to large scaled farming. Increases in the NT's population and the demand for rural living and lifestyles have seen the encroachment of peri-urban developments in the region including the subdivision of larger blocks for smaller rural blocks. Water supply to Berry Springs residents is totally reliant on surface water extraction from creeks and rivers or from the aquifer via individual bores.

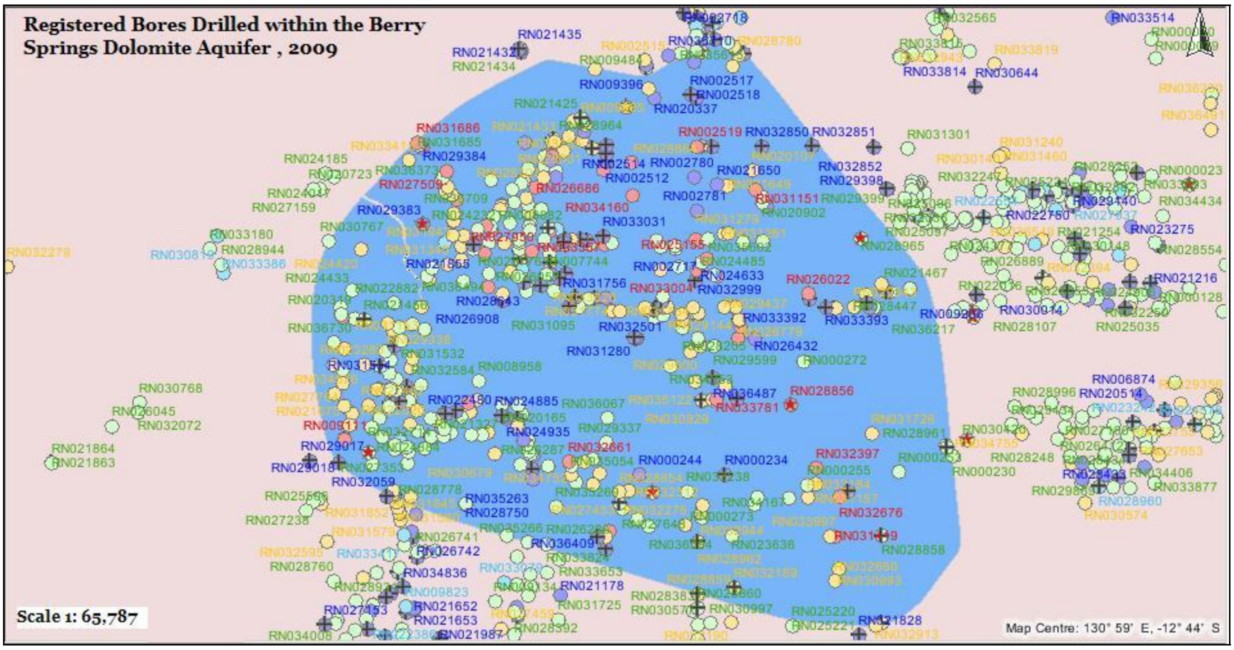


Figure 3 -3 ***Registered Bores Drilled within the Berry Springs Dolomite Aquifer (shown in blue), 2009***

Rural residents and medium to small scaled farms to date have not been subjected to metering and licensee of water use. Only a handful of larger scaled horticulture and aquaculture farms are regularly licensed and monitored. Water demand in conjunction with the above-mentioned issues is placing pressures on a resource where little is known

4. Geological Settings Of The Berry Springs Region

Berry springs lies on the Batchelor Shelf on the western section of the Pine Creek Geosyncline. Local geology is controlled by geologic structures. Early Proterozoic sediments were deposited on the slopes of the dome of the Rum Jungle Complex (Ar) of the Archean age, displaced by the Giants Reef Fault and then tightly folded. Tight folding has resulted in the creation of a small oval shaped basin structure where younger proterozoic carbonates were then deposited, and is evident when examining bore log RN28856 (NRETA Maps, 2009). Signs of folding and faulting can be witnessed in the east and south east sides of the Berry Springs/ Noonamah area where the east-west strike changes to almost north south (Verma, 2001).

Regional sediments of the Finniss River (P4), the South Alligator (P3) and the Mount Partridge Groups (P2) underlie Berry Springs and surrounding areas. Cretaceous sediments (K) mostly overlie the South Alligator Group of rocks, occasionally the Finniss River Group and Mount Partridge Group rock (Verma, 2001). Cainozoic sediments cover most areas albeit hills and steep slopes. The Ella Creek Formation is limited to a very small coverage area.

The Rum Jungle Complex (Ar) is the oldest rock in the area, occurring as a dome consisting of leucocratic granite, large feldspar granite; course granite, meta-diorite, granite gneiss, schist and gneiss; and banded iron formation. Early Proterozoic sediments are deposited is areas surrounding the domes. Groundwater has little to no potential in these rocks.

The Mount Partridge Group (P2) rocks are exposed above ground level at the southern boundary of the South Alligator Group where topographic elevation is high on the steep slopes of the Archean rocks and displacements of rocks by the Giants Reef Fault can also be witnessed in the region (Verma, 2001). This group is comprised of rocks from the;

a) Crater Formation
b) Coomalie Dolomite
c) Whites Formation
d) Acacia Gap Quartzite Member, and;
e) Wildman Siltstone Formation

Regional formations related to the study site are highlighted in Figure 4-1.

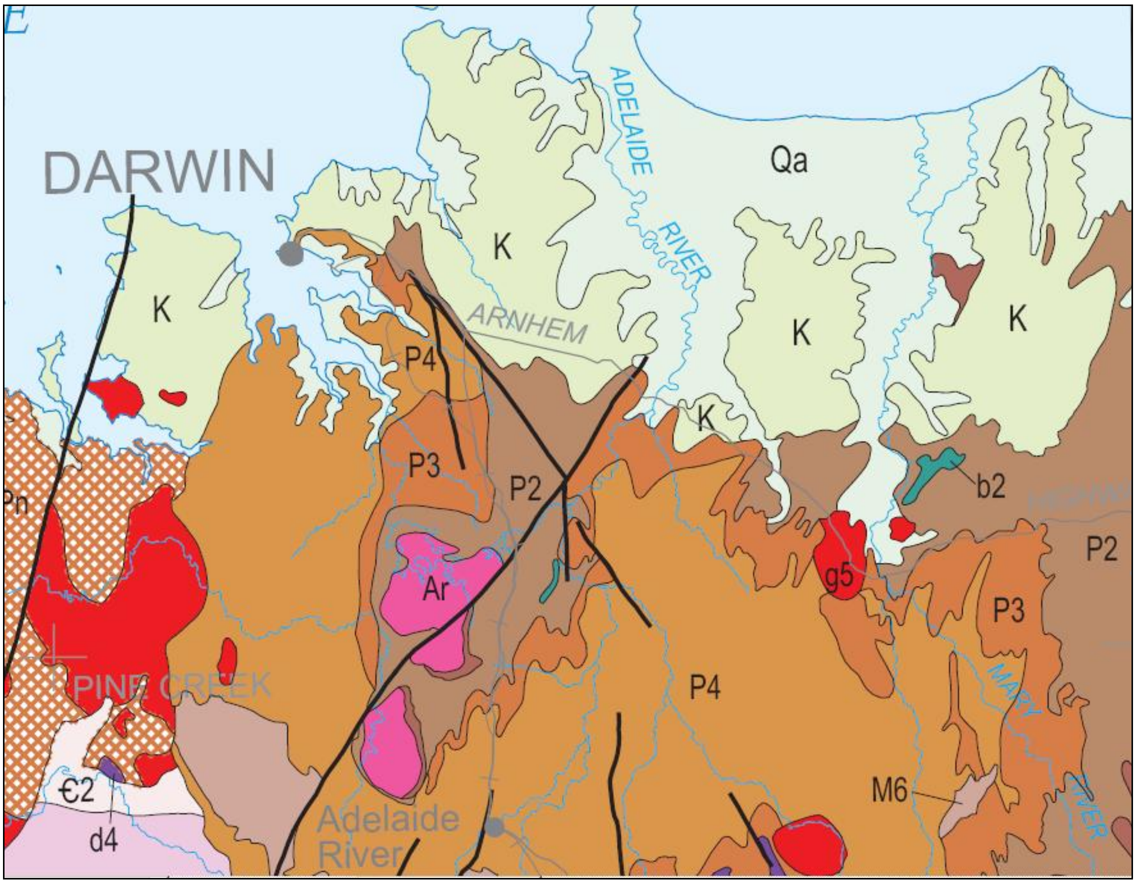


Figure 4-1 Regional Geology of the Berry Springs/ Noonamah Area

5. Geological Settings Of The Berry Springs Study Site

Descriptions of geological features with specific relevance to the study site are listed below in depositional order;

1) Bathurst Island Formation (Darwin Member)

Is of the lower Cretaceous age and unconformably overlies proterozoic age rocks. Rocks in this formation consist of kaolintic claystone, silty in places, glauconitic and calcareous, basal conglomerate, clayey sandstone and sandy claystone, radiolarian, montmorillonitic. Groundwater potential in this formation is very low and this formation, like the Depot Creek and Petrel Formations is good in assisting as a recharge medium for underlying dolomite aquifers.

2) Petrel Formation

Is of Jurassic age and overlies the Depot Creek Formation. This formation consists of rock types such as friable quartz sandstone, quartz pebble conglomerate, conglomerate sandstone, ferruginous sandstone and minor breccias. This formation is very porous and good in recharging underlying areas but groundwater potential is extremely poor in this formation.

3) Depot Creek Sandstone of the Tolmer Group

This formation lies unconformably over lower proterozoic sediments and is not exposed at ground level. Rock types of this formation consist of pink quartzite, quartz sandstone with ripple marks. Water worn quartzite and sandy layers have been intersected during drilling indicating that this layer may act only as a medium for recharging the underlying the dolomitic aquifer. Groundwater potential for this aquifer is poor.

4) Dolomite Undefined Layer

Typically overlies the South Alligator Group and the Mount Bonnie Formation and is exposed along springs inside the Territory Wildlife Park (near monitoring Site 5), Berry Springs Nature Park (downstream of monitoring Site 1) and in the section of Berry Creek adjacent to the Hopewell Road Crossing. Rock types consist of silicified dolomite, dolomite siltstone, saccharoidal quartzite (after carbonate), calcite crystals, siltstone, shale, phyllite (commonly carbonaceous, pyretic, cherty and siliceous). Origins of this formation have been debatable in previous studies. For the purpose of this study it is defined as the undefined layer found within the top layers of the south Alligator Group. Groundwater potential for this formation is generally 75.0 L/s and may be even higher if fracturing or weathering is present. The highest sustainable yield recorded for bores drilled within this aquifer was noted at 32 L/s (Verma, 2001). On the eastern boundaries of the Dolomite, a small graben with a trending orientation north south and highly sheared by the Burrell Creek Formation occurs. Verma (2001) states that yields of bores drilled in this graben are comparatively higher that the average yield elsewhere in this formation.

5) Wildman Siltstone

Deposited in a shallow marine environment. Rocks types consist of laminated colour-banded shale (pyretic and carbonaceous at depth), silty shale, siltstone, sandy siltstone, minor silicified dolomite, fine quartzite and medium to course grained sandstone (pyretic in places). The groundwater potential of this formation is generally limited to 0.5 L/s but may be higher if weathering and/or fracturing are present.

The nature of local geological structures, parent rock types in combination with topography and regional rainfall is responsible for the driving forces forming dolomitic karst aquifer systems associated with Berry Springs of which these characteristics are discussed in greater detail in Sections 4 and 5.

6. Hydrogeological Characteristics Of Berry Springs Dolomite Aquifer

A study was carried out by M.N. Verma for the Northern Territory Government Water Resources Division in 1994 on Groundwater Resources of the Berry Springs- Noonamah Area. The purpose of the study was to investigate and establish boundaries of both the major and minor aquifers in the Berry Springs-Noonamah region. During this investigation twenty-eight bores were drilled, with ten bores constructed as monitoring bores within the region.

Findings of Verma's Study conducted in 1994, revealed a major dolomite aquifer with an average depth 20m below ground level (bgl) was established covering approximately 20 x 20 km^2 area with aquifers occurring within two distinct facets;

(1) The unconformity of the South Alligator undefined dolomite layer (Psd) and overlying Cretaceous sediments (K) and in the weathered fractured dolomite layer and;

(2) In joints and fractures in dolomite, this has been detected up to 199.0 m bgl, presenting on average sustainable yield of over 5.0 L/s. Although it is also found as high as 32 L/s sometimes the yield can be markedly lowered due to the presence of clay and/or fine sand in the aquifer (Verma, 2001).

Verma's findings (2001) determined that this particular aquifer system is responsible for maintaining surface water flows for features such as Lake Deane, Berry Springs, Parsons Springs and Twin Springs. A number of creeks (Some of those associated with the above mentioned springs) are sustained during the dry season by groundwater discharge.

Understanding the functioning of the unsaturated zone of carbonate aquifers and general rock properties is important as it determines the passage of water towards the aquifer, its involvement in the karstification processes, storage capacity and in the types of water flow that may occur within the aquifer system. Moreover as water flows through this zone towards the inner part of the system it is mineralised and the input signal is homogenised, for example the chemical and isotopic differences of the rain water are reduced (Jaques, 2008).

Jaques (2008) claims that two types of infiltration can be distinguished in the unsaturated zone of carbonate aquifers;

1) The first of these corresponds to the circulation of water through karst conduits, which ensures the rapid transit of water towards deeper zones with relatively high but short-lived flow volumes.

2) The second type features the slow circulation of water through the matrix bedrock and fissures with a small flow volume and a low velocity.

The Berry Springs dolomite aquifer is representative of a type 2 infiltration process presented by Jacques (2008). Pure dolomite contains 54.28 percent calcium carbonate and 45.72 percent magnesium carbonate. Concerning dolomite's crystallography, crystals typically form rhomobhedral (Hexagonal System), curved saddle-shapes in groups.

Generally occurring as pink pearl spar, it can occur in clear, white, grey, tan, or black, depending on its formation with related carbonate forming cation substitutions. For example, with a substitution of iron (Fe) for magnesium (Mg), brownish ankerite, Fe $(CO_3)_2$ crystals will form. With a relative hardness of 3.5-4, its differentiation from calcite can be determined by acid test.

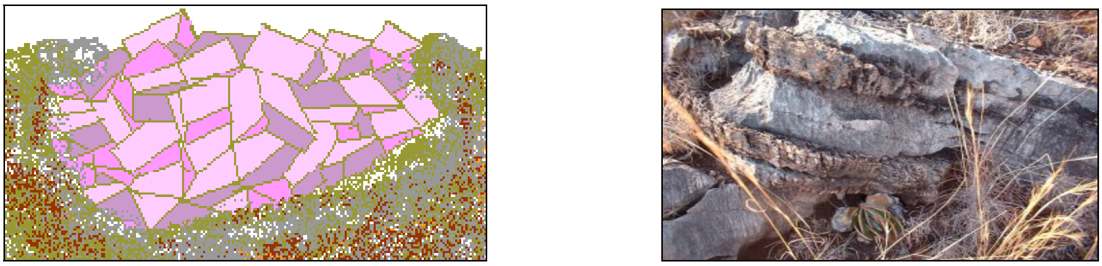
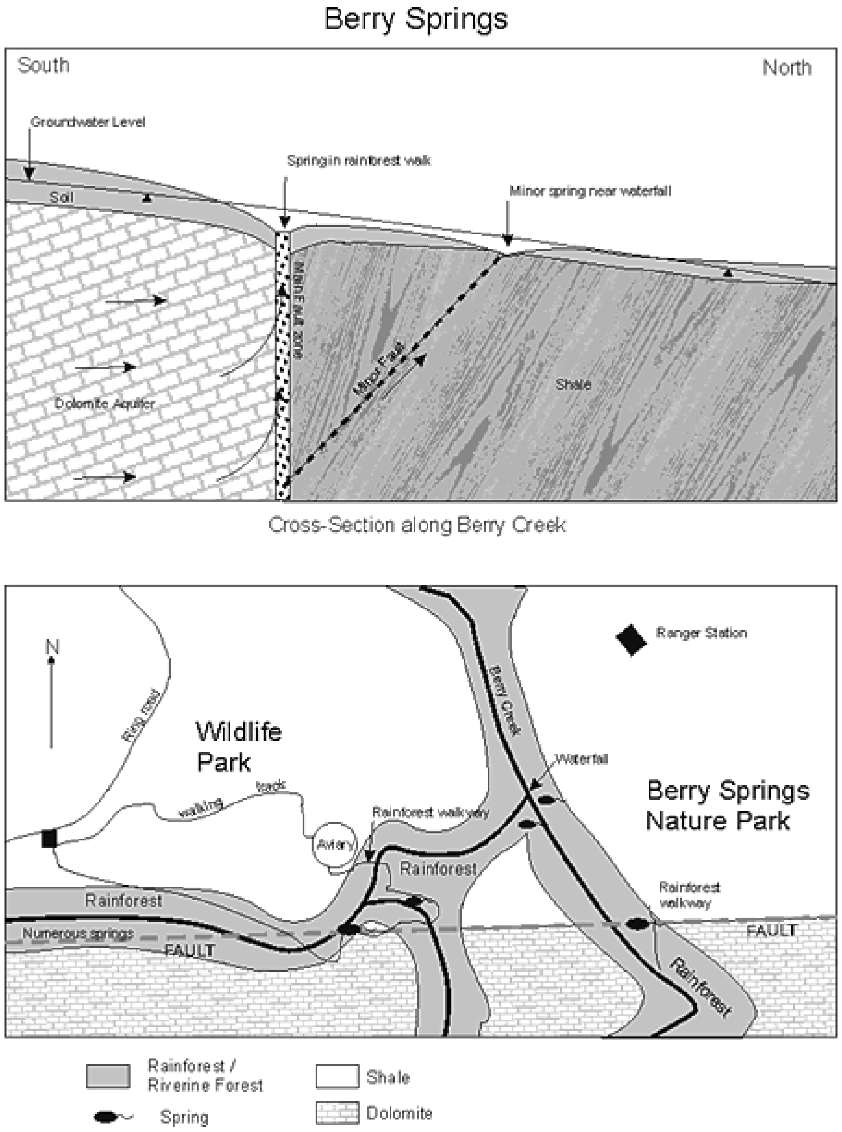


Figure 6-1 Example of Schematic and Field Representation of Weathered Dolomite.

The primary occurrence of Berry Springs can be attributed to localized faulting along the geological boundary between the Dolomite and Burrell Creek formation. Verma (2001) states that the fault can be traced by following the breccian along this fault and that more minor springs (fed by the hyporrheic zone) along berry creek occur due to topographic lows, not from this fault. Schematic diagrams of major and minor spring formations at Berry springs are represented in Figure 6-2.



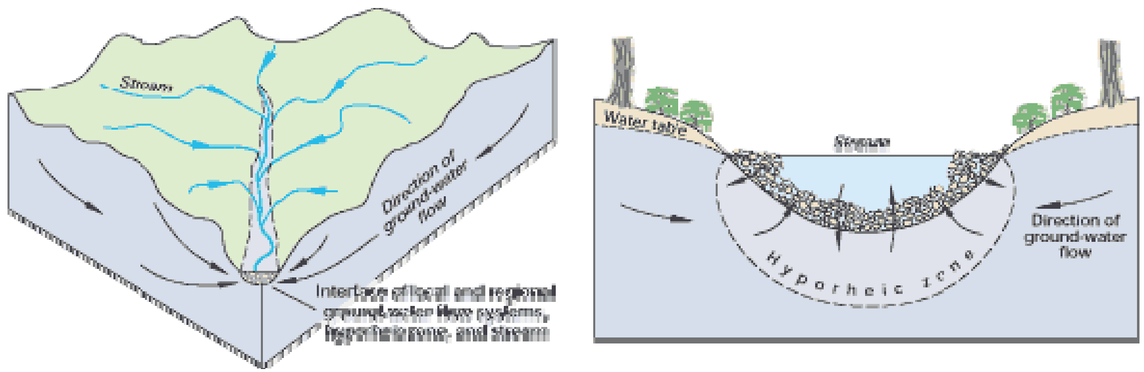


Figure 6-2 Schematic Diagrams of springs formed by faulting and minor springs formed by topographic lows, Berry Springs NT

Studies by Verma (2001) have also concluded that generally the Burrell Creek Formation is fractured over its entirety and therefore water supply may exceed higher than average yields of 0-5 L/s in these rocks.

Berry Springs is fed from a major aquifer that primarily exists within this weathered layer comprised mainly of basal conglomerate, course sandstone, some clay, silt and sand of the cretaceous sediments and weathered and fractured silicified dolomite in the upper karstic layer of the of the undivided Dolomite layer (Verma, 2001). Depth of this aquifer varies from 10-88m below ground level (bgl). Due to the location of the aquifer in a small basin, depth is variable dependent on geographic location. Average thickness of the aquifer determined by drilling during Verma's Study (2001) was shown to be 50, with exposed units visible at discharge points at Berry Springs and Parsons Springs at a topographic low of 7-0 m AHD.

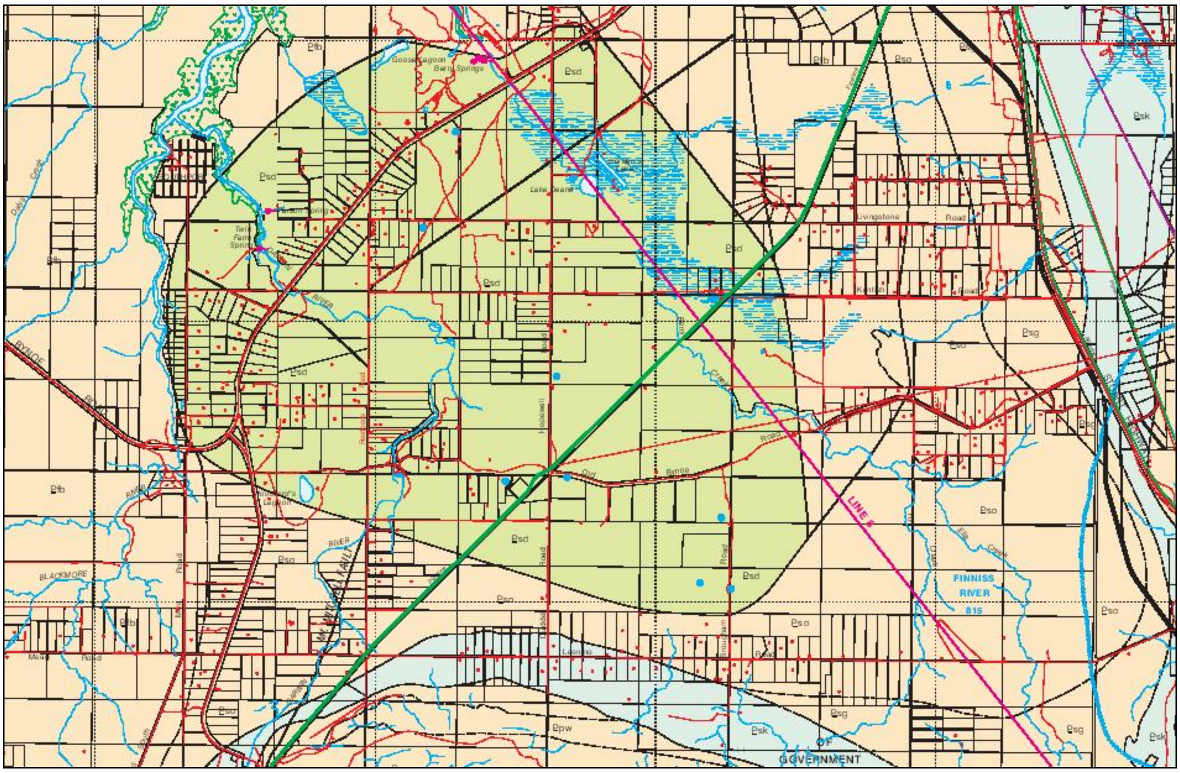


Figure 6-3 Extent of the Undefined Dolomite Aquifer at Berry Springs (shown in green)

Groundwater movement was documented by Verma (2001) by correlating rainfall data and measuring standing water levels in 5 monitoring bores. Verma (2001) describes the movement of groundwater both during the wet and dry seasons is towards the Parsons Springs and Twin Farm Springs in the northwest where the topographic elevation is low and within the tidal zone and towards Berry Springs in the north as shown by the water contours of both the dry and wet seasons in Figure 1-4. Verma (2001) has calculated groundwater slope during the dry season as 0.68 m.km (4.4 m drop in 6,500 m) and during the wet season a rate of 1.37 m/km (8.91 drop in 6,500 m). It is evident from these calculations that wet season groundwater gradient is almost twice that of dry season groundwater gradient and discharge from springs, lagoons, creeks and rivers is significantly high during the wet. Wet season observations show that runoff is also very significant during the wet season, a good indication of aquifer saturation, therefore indicative of annual recharge via rainfall.

Verma (2001) claims that water quality in the Berry Springs area varies significantly from one aquifer to another; with results showing that;

- Average pH levels range from 5.4-7.8;
- TDS varies from 25-200 mg/L;
- Chloride generally low ranging from 2-10 mg/L
- Sodium is low ranging from 2 to 6 mg/L

Shown below in Table 6 are the typical chemical contributions of major aquifer responsible for supplying groundwater flows to Berry Springs as provided by Verma (2001).

Aquifer / Ion	**pH**	**TDS**	**Ca**	**Mg**	**Na**	**K**	**siO_2**	**Cl**	**SO_4**	**F**	**HCO3**
Fractured & Karstic Rocks	7.8	200	35	28	2	1	15	5	8	0.1	250

Table 6-4 Typical Chemical Contributions of Fractured & Karstic Rocks (Psd, Ppc) of the Berry Springs Undefined Dolomite Aquifer (Verma, 2001)

An analysis of water quality data, including Ca^{2+} and HCO_3 ions, Mg, Na, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Alkalinity and Hardness and their relevance in determining origins and assistance of groundwater in maintaining surface water flows at Berry Springs is presented in detail in Section7. Analysis of flow gauging data, standing water level data in observation bores and regional rainfall data is also discussed in greater detail in Section 7.

7. Influence Of Climate And Hydrology On Dolomite Karst Aquifer

The Top End of the Northern Territory is known for its distinct wet and dry seasons which are mentioned throughout the discussion paper, with more than 90% of the rainfall occurs November – March which is described as the Wet Season. The Dry Season (Apr – Oct) is known for its lack of rain and flows from rivers are directly dependent on discharge from the aquifer.

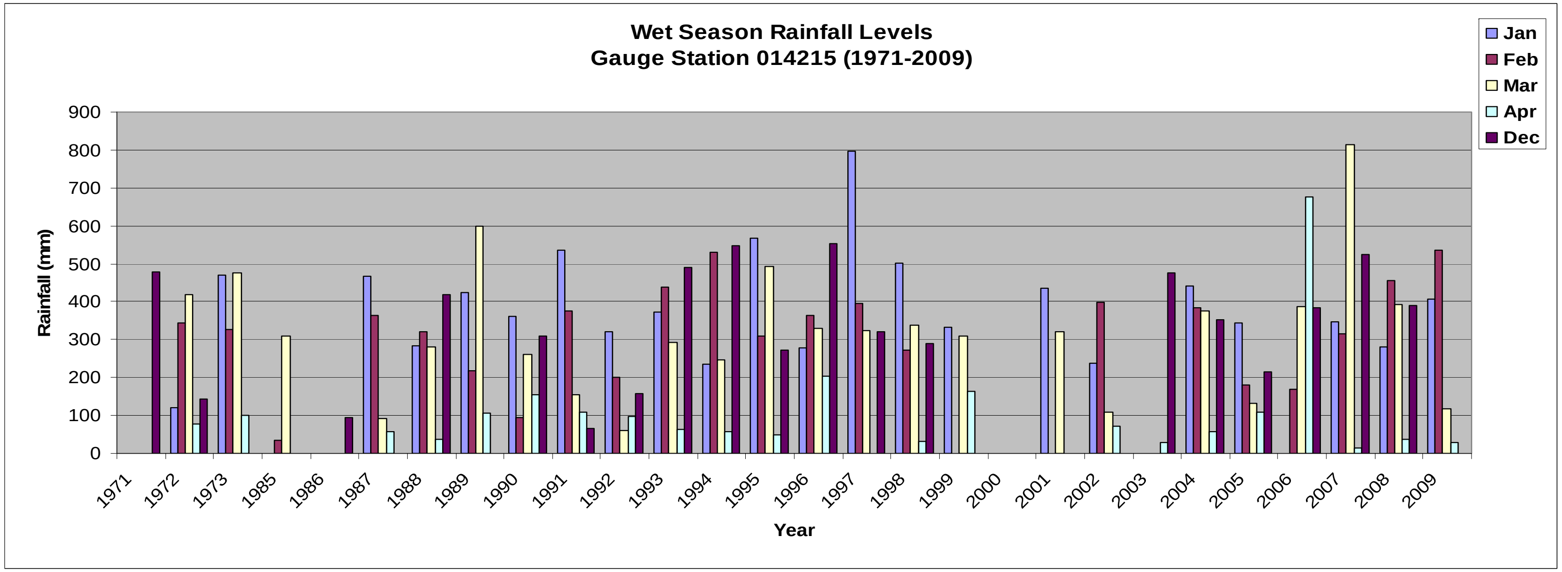
Mean annual rainfall recorded at the Berry springs Ranger Station recorded from 1971-2009 was 1783.5 mm/year. Evaporation levels vary from 200-175 mm during months of higher rainfall (wet season) AND FROM 175-200 mm during drier months of the year (dry season. The months of October and November present the highest rate of evaporation at 250 mm/ month in conjunction with variations of rainfall between 0-70mm respectively. October is considered to be the month of most importance in monitoring sustainable levels of groundwater availability and flow for Groundwater Dependent Ecosystems as evaporation far exceeds participation

MONTHLY AVERAGE CLIMATE STATISTICS- BERRY SPRINGS, NT			
Month	Highest Rainfall (mm)	Lowest Rainfall (mm)	Evaporation (mm)
January	389.0	119.1	175
February	319.3	33.0	150
March	318.1	58.8	175
April	101.3	1.2	175
May	14.3	0.0	175
June	0.1	0.0	175
July	0.8	0.0	175
August	1.9	0.0	200
September	14.1	0.0	200
October	70.4	0.0	250
November	164.6	37.2	250
December	341.2	64.6	200

Table 7-1 Rainfall Statistics for Berry Springs (1960-2009)

Hydrology is driven by drainage to the north-west by a plethora of water bodies including creeks, rivers, lagoons, springs (both perennial and intermittent). Hydrological features of the region include;

- Major Rivers- Darwin River and Blackmore River
- Major creeks- Ella Creek and Berry Creek
- Springs- Berry Springs, Parsons Springs and Twin Farm Springs
- Lagoon Systems- Woodfords Lagoon and Lake Deane
- Numerous Soaks
- Artificial Water Bodies- Goose Lagoon (Northern Territory Wildlife Park.)



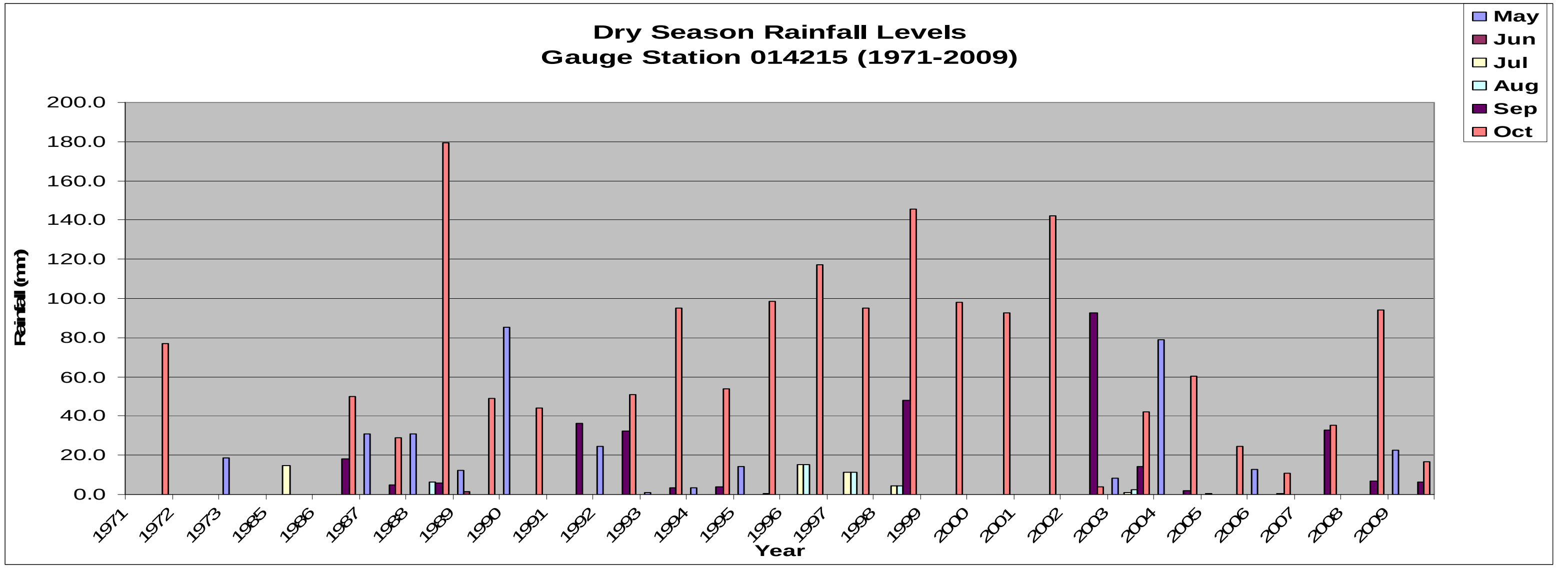


Figure 7.2 Wet Season and Dry Season Rainfall Patterns from 1971-2009.

Figure 7-3 shows variations in elevations of Berry Springs, demonstrating elevations of 0-25 m at 2008/2009 sampling sites located at the low reaches of the catchments. Elevations of the Berry Springs vary greatly in excess of 100 m to as little as 0 m elevation.

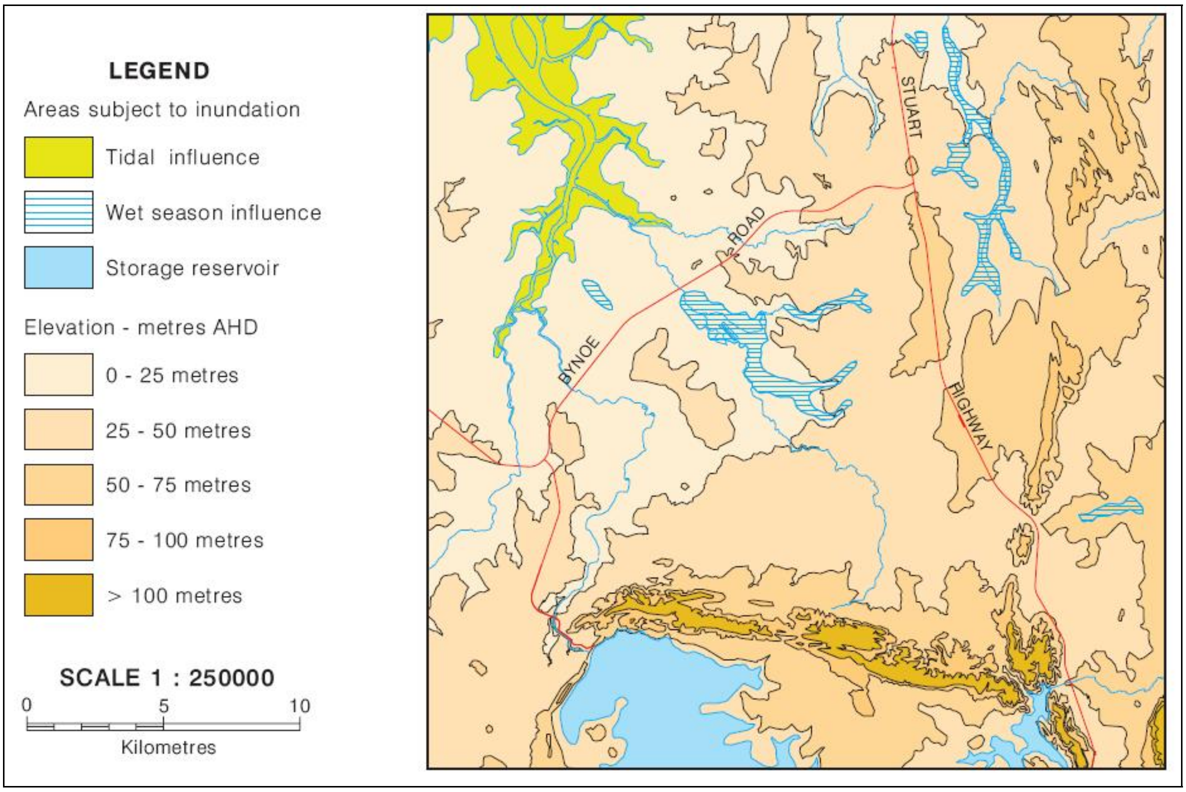


Figure 7-3 Physiographic Map of Berry Springs

Karts are landscapes formed on carbonate rocks such as limestone, dolomite and marble or on evaporites gypsum, anhydrite and rock salt. Landforms of a karstic nature are comprised of characteristics such as closed surface depressions, a well-developed underground drainage system, and a paucity of surface streams.

Karstic formations in carbonate rocks are formed by the dissolution of kart rock types by acidic water occurring when rainwater, carbon dioxide (CO_2), and decaying organic matter in the soil interact becoming increasingly acidic, percolating through fractures and dissolving rock. When the bedrock becomes saturated with water, dissolution continues as the water moves sideways along bedding planes and joints in the rock itself. These conduits enlarge over time, and move the water, via a combination of gravity and hydraulic pressure, further enlarging the conduits through a combination of dissolution and abrasion of the surrounding rock.

Varied interactions among chemical, physical and biological processes can result in a broad range of geological effects including dissolution, precipitation, sedimentation and ground subsidence in karstic rocks. Diagnostic features such as large springs are the result of dissolutional actions of circulating groundwater, which may exit to entrenched effluent streams, at times depending on water availability can feed such stream throughout drier periods of the year.

Carbonate karst can be either a sink or a source of CO_2. The karst process is a component of the global carbon cycle where in which carbon is exchanged between the atmosphere, surface, groundwater and carbonate minerals. The dissolution of carbonates enhanced by the presence of acids in water, bond to carbon derived from the rock and from dissolved CO_2 as aqueous HCO_3-. The deposition of dissolved carbonate minerals is then followed by the release of some of the carbon as CO_2. In many karst locations, CO_2 emission is associated with the deposition of calcareous sinter (tufa, travertine) at the outlet of cold or warm springs.

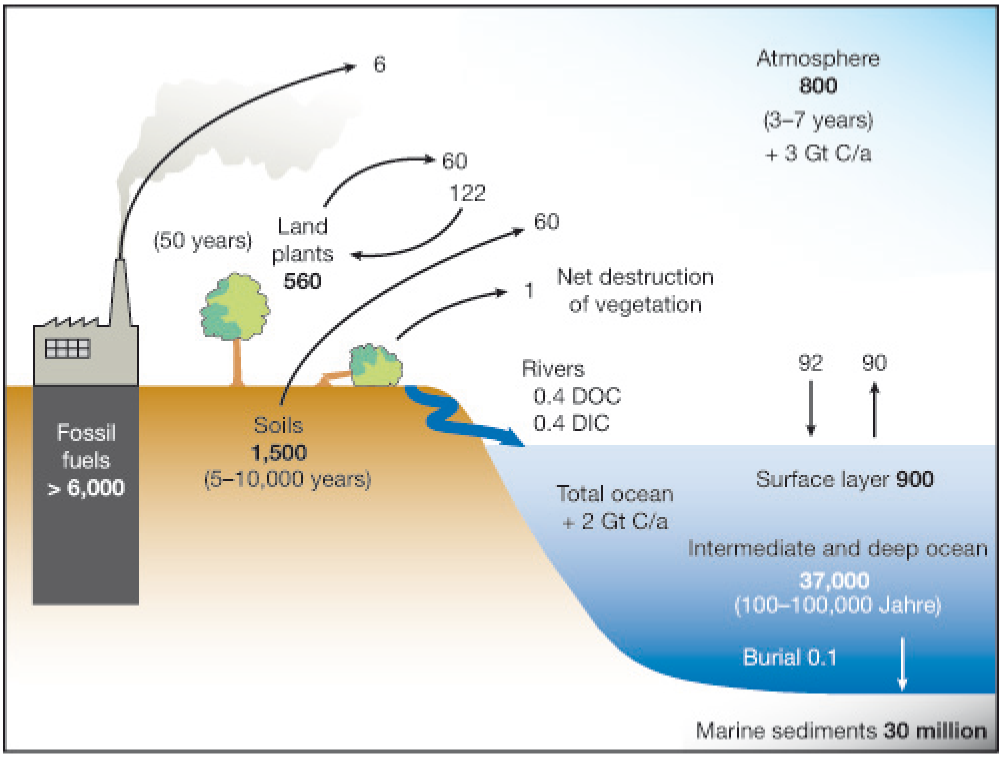


Figure 7-4 Global Carbon Cycle

Karst is most common in carbonate terrains in humid regions of all kinds (temperate, tropical, alpine, polar), but processes of deep-seated underground dissolution can also occur in arid regions.

8. Methods

8.1 Site Selection and Monitoring Surface Water Spring Discharge

An initial field survey of Berry Springs was conducted in February 2008 to determine scope, methodology and suitability of sampling sites for a project of this nature.

Initiation of Berry Springs as the study site was stimulated for the need for a better understanding of the undefined dolomite aquifer (or the Berry Springs dolomite aquifer) in the event of upcoming intentions by the Northern Territory Government to undertake water allocation planning under National Water Imitative for Darwin's urban, peri-urban and rural lining areas. Berry springs has long been a much-loved place of recreational and environmental significance due to access to water and unique flora and fauna all year round to locals and Indigenous groups as well as an area of interest to the agricultural industry due to availability of high groundwater yields. Due to this social and economical interest, the Northern Territory Government has acknowledged the need for strategic planning and policy representative of harmony between the sustainable preservation of social and environmental water values in harmony with economic aspiration of the region.

Site selection for sampling and gauging were limited by factors such as;

- Accessibility to sites
- Stream depth and width
- Known or suspected spring discharge areas
- Disruption of sample sites by recreational uses
- Field hazards such as Saltwater Crocodiles
- Sacred Site and Indigenous cultural issues

In March 2008, 5 sites in total were chosen for monitoring. Water quality and gauging sites were chosen according to accessibility, suitability of channel width and representative of spring activity along Berry Creek. Gauging was limited to only 3 of 5 monitoring sites due to safety (presence of Saltwater Crocodiles) and suitability of left and right banks for gauging. Sites 3 and 4 were excluded from flow gauging due to the above mentioned limitations.

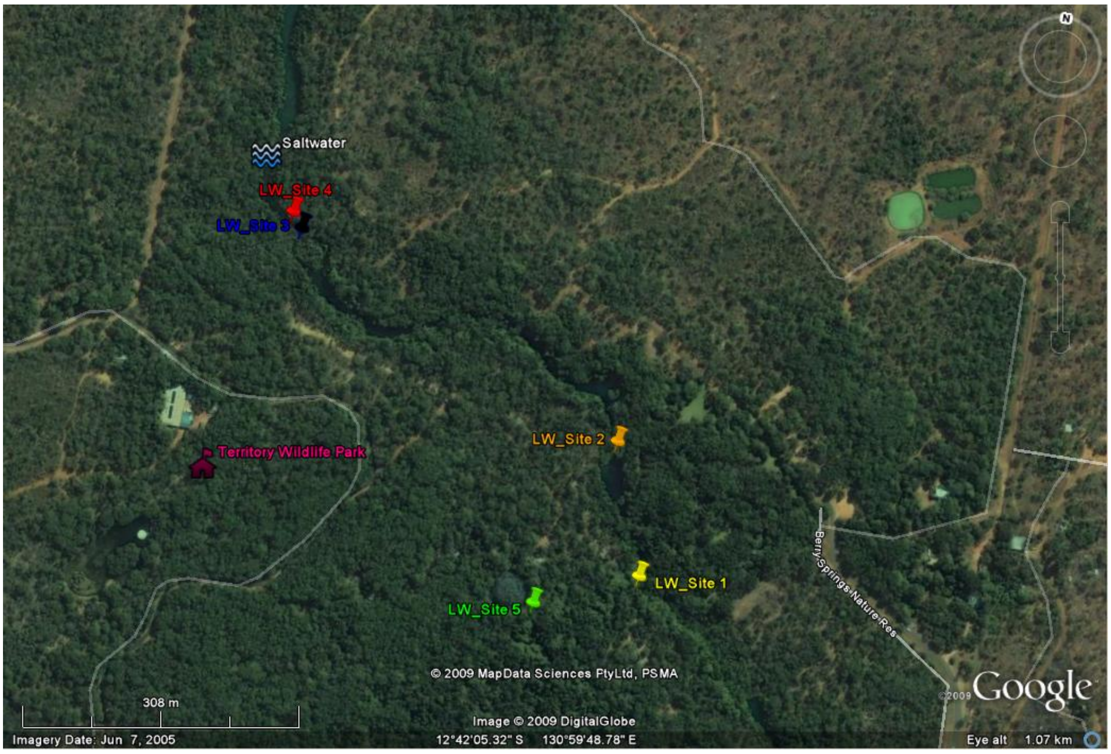


Figure 8.1 Berry Springs Sample Sites for the 2008-2009 (Google Earth, 2009)

Site 1 is located on a tributary arm of Berry Creek leading from the Territory Wildlife Park into the Berry Springs Recreational Reserve (waterfall swimming area). Spring discharge at site one was evident through hyporrheic zone and dry season surface water flow from larger fractures located at higher elevations above Site 5.

Site 2 was selected downstream of Site 1 in a narrow stream channel adjacent to the swimming platform of the Main Pool at the Berry Springs Recreational Reserve. Spring discharge at this site was evident through dry season flows.

Sites 3 and 4 were selected downstream of the main pool and secondary pools along Berry Creek either side of a weir that separates freshwater flow from saltwater tidal influence. Site 3 represents freshwater readings and Site 4 represents a mixture of freshwater and saltwater confluence. Samples at Site 3 and 4 were limited to areas of safety due to the presence of saltwater crocodiles.

Site 5 was selected upstream from Site 1 located in the Territory Wildlife Park downstream from the head of a series of springs with cultural significance to local Indigenous people (a woman's dreaming site). Cultural issues prohibited entry into water at this site. Samples were taken off adjacent stream banks or through the use of the elevated boardwalk built as part on a monsoon walk exhibition for the Park. At times gauge readings where hard to obtain using only the ADCP Boat. In circumstances such as this a flow data logger would have been more suitable however cultural issues prevented entry to water which was required to undertake this task. Photo plates of sample sites and Berry Springs can be viewed in Appendix B.

Hydrological and geochemical measurements of springs, sinking streams, drip waters into caves, and cave streams provide records of short-term changes in water quality and chemical processes. The most important variables include pH, temperature, Ca, magnesium (Mg), sodium (Na), Chloride (Cl), Calcium Carbonate (HCO_3) and sulphate (SO_4). Gypsum denudation could be measured by the amount of hydrated calcium sulphate (Ca SO_4 $2H_2O$) (m^3 from $1km_2$ per year) carried away by underground runoff. Salt dissolution can be estimated in a similar way.

In-situ field sampling using a multi-parameter water lab was conducted at monitoring Sites 1-5 were undertaken on a monthly basis between April 2008 and October 2009, often coinciding with gauge data collection. Parameters investigated during in-situ field testing include monitoring of temperature, pH, electrical conductivity (EC), dissolved oxygen (DO), percentage of dissolved oxygen (DO%) and turbidity (NTU). Sampling was undertaken on a monthly basis to predominately capture changes between wet season flows and dry season flows.


Plate 8 -2 Multi Parameter Hydrolab

1L grab sampling was conducted at monitoring Sites 1-5 in July 2008, September 2008, February 2009 and October 2009 and sent for lab analysis to the Water Chemistry Lab, Department of Department of Resource Development, Primary Industry, Fisheries and Mining for independent testing. Grab sampling was limited to funding constraints for lab sampling. Physical and chemical parameters were tested for field assurance and to provide information in relation to water chemistry that could not be tested during in-situ field monitoring. Main parameters of interest include pH, temperature, dissolved oxygen (DO), calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), bicarbonate (HCO_3), total dissolved solids (TDS) and electrical conductivity (EC).

8.2 Measuring Surface Water Spring Discharge

Gauge flow readings were conducted for Sites 1, 2 & 5 to assist in determining flux of surface water flows discharged from springs and overland flow during 2008-2009. Due to access issues and flooding gauging was limited to the months April- October when monitoring and swimming areas were accessible to the public. Readings were conducted from April 2008-October 2008 and April 2009- October 2009 using a stream probe fitted with ADCP sensor (during higher water levels) and a pygmy flow meter with data logger (during lower water levels). Data was logged in WinRiver and flux determined in M3/s.

Plate 8-3 Pygmy Flow Meter & Data Logger (left) and Stream Probe (right)

Historical gauge data pertaining to water quality and flow were also provided by the Hydrographic Team within the Department of Natural Resources, Environment, the Arts and Sport for analysis for stations G8150171, G8155172, G8150027, G8150028, G8155114, G8155088.

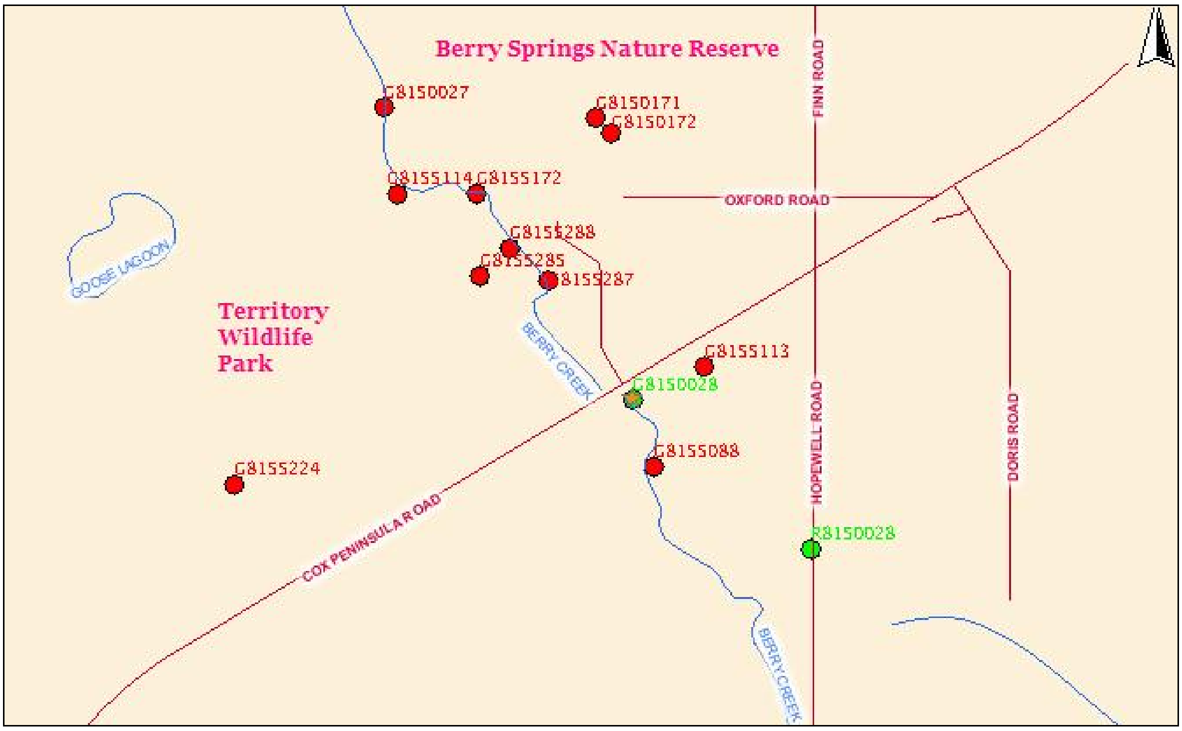


Figure 8-4 Location of NTG Gauging Stations (operational stations in green)

8.3 Analyzing Bore Data

Due to time availability and resources in-situ field monitoring and lab analysis were limited to surface monitoring at Berry springs. However discussions were held with groundwater monitoring technicians within the Department of Natural Resources, Environment and the Arts who in which conduct regular water monitoring programs in observation bores Across the NT. Standing water level monitoring data was provided for observation bores RN 29385, RN28965, RN28964, RN28863, RN28856by the Department for analysis in this study. Standing water level data will assist in correlating bore water behaviour in relation to contour height and rainfall data.

Further information pertaining to current and historical water quality in these bores was obtained through NRETAS Maps (www.nt.gov.au/nretas/nretasmaps). Parameters of interest within this data include pH, temperature, dissolved oxygen (DO), calcium (Ca), magnesium (Mg), sodium (Na), chloride (Cl), bicarbonate (HCO_3), total dissolved solids (TDS) and electrical conductivity (EC).

Understanding chemical and physical parameters in observation bores could assist with correlating origins of surface water and assisting providing evidence of links between surface and groundwater. However this data can be highly variable dependent on ore water sampling methods as if sampling in not frequent and bore water sampled not pumped effectively for clearance of stagnant water in the collar before sampling, chemical results can often represent increased loadings of minerals encrusted on screens (such as iron or calcium).

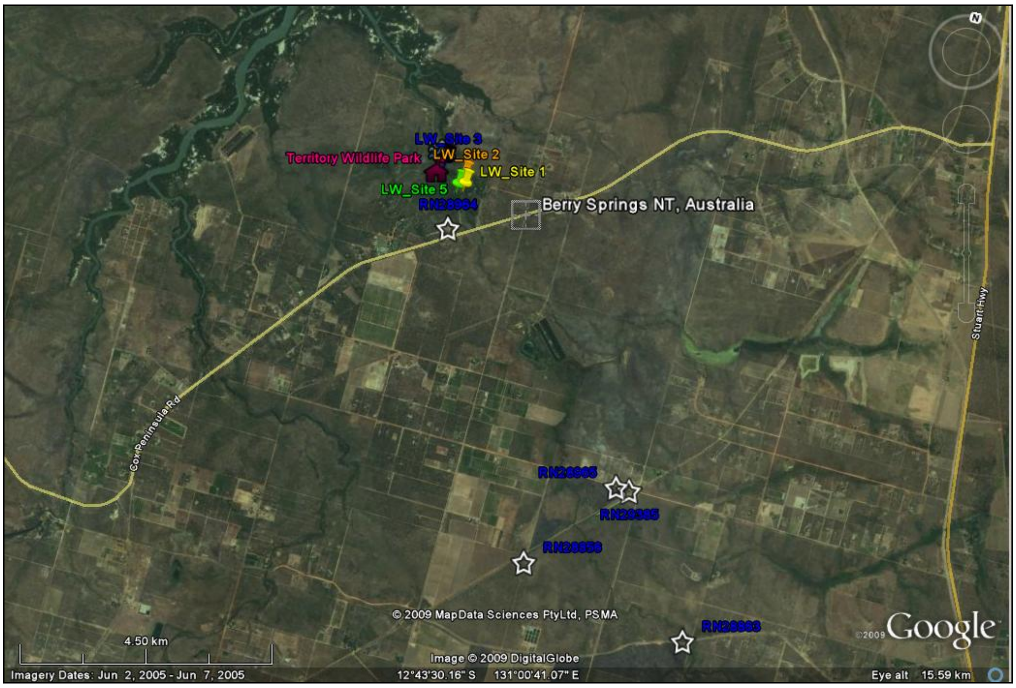


Figure 8-5 Location of Observation Bores in Relation to Sample Sites

8.4 Stream Condition Assessment

Observational field data collection conducted at Sites 1-5 also included the use of AUSRIVAS and TRARC methodologies to assess stream condition and site suitability.

Ausrivas is a qualitative physical assessment tool used to assess stream condition. It is a toolbox for standardised protocol for the consideration of stream condition, looking in depth at physical and biological attributes. It is a stand-alone method of physical and geomorphologic assessment and involves 3 stages; evaluation of physical stream assessment methods used in Australia, a habitat assessment workshop and derivation of final recommendations for standardised assessment protocol to formulate a method of assessment with the ability to encompass a range or river types in the Australian landscape.

The physical assessment protocol works in a similar manner as the Ausrivas Biological Assessment Tool for River Assessment (Parsons et al, 2002). Physical, chemical and habitat information is collected from reference sites and used to construct predictive models, which in turn, are used to assess the condition of test sites. The physical assessment protocol comprises of the following major components:

- Reference Site Selection- site representing 'least impaired' conditions are selected, and stratified to cover a range of regions and geomorphological river types.

- Data Collection- Each reference site is visited once and physical, chemical and habitat variables are measured using standardised methods.

- Model construction- Predictive models are constructed using AUSRIVAS. However in the physical assessment tool large scale catchment characteristics are used to predict local scale features. Therefore the outputs of a physical predictive model are based on the occurrence of macro invertebrate taxa.

- Assessment of test sites- Assessment of stream condition involves the collection of local and large-scale physical, chemical and habitat data from test sites. The information is then entered into predictive models and observed: expected ratio is derived by comparing the features expected to occur at a site against the features that were actually observed at the site. The deviation between the two is an indication of physical stream condition.

- Functional Zone Type Descriptions for Rivers

  Assessing functional zone types for rivers and streams can assist greatly in understanding stream behaviour, water chemistry and land-use impacts. Monitoring sites established for this study fall within the Functional Upper Zone A.

In the functional Upper Zone A (low energy confined) is characterised by long pools separated by short channel constrictions (i.e. chain of ponds morphology). The pools form upstream of the channel constrictions and are dominant morphological feature in this zone (Parsons et al, 2002).

They are generally associated with major bedrock bars that extend across the channel or substantial localised gravel deposits that act as riffle areas (Parsons et al, 2002). Local riverbed slopes increase significantly at these constrictions representing small areas of generally high energy that contrast with relatively low bed slopes and energies of the pool environment. Overall bed slope in the upper section of zone A is in the order of 0.0001 with a corresponding stream power in the order of 1.5 W/m2. Stream power (W) is related to the rate in which sediment movement will occur or at which energy is expended in a stream or river (Parsons et al, 2002).

A platform configuration of zone A is controlled by valley morphology. Generally the river channel may have a small flanking floodplain because of narrow valley floor configuration, and therefore conditions limit floodplain development. Bankfull channel dimensions can be up to 30m in width, 3-4m in depth/height and may have a width depth ratio of up to 10. Bankfull channel capacities do not generally exceed 30 m3s-1 (Parsons et al, 2002).

The method applied in undertaking this assessment requires site specific assessment of physical characteristics of desired monitoring sites. This assessment includes a planform sketch of the site, assessment of basic water chemistry, stream features, local impacts, riparian zone composition, and disturbance ratings in stream characteristics, bedform features, and stream gradient. Use of the AusRivas physical assessment protocol method and field data sheets in this study has allowed for in-depth insight into characteristics of sample sites to allow for efficient planning for effective monitoring prior to commencement of this study.

8.5 TRARC

The Tropical Rivers Appraisal for River Condition (TRARC) is a multi index which is comprised of a number of summary metrics (sub-indices) that that are combined to derive a single index of riparian condition. Multi-meric approaches are often commonly used for accessing vegetation condition and river health and are appealing as they provide an integrated summary based on a number of different merits that may influence condition. Caution must however be conducted when interpreting the final index score as they may have different sub-indicie scores (when comparing the two sites) and require very different management needs.

Riparian zones can be defined as land the land in which adjoins or directly influences a body of water whether that includes lagoons, floodplains, rivers and wetlands (Dixon et al, 2006). For this study on Berry Springs, riparian vegetation can be considered to encompass vegetation from the low water mark of the stream channel to areas influenced by elevated water tables during wet season or those impacted by flooding. Riparian zones are important features of a landscape providing and influencing the flow of a landscape providing and influencing the flow and availability of nutrients to regional biota, provide functions to help maintain aquatic ecosystems (freshwater and marine) and in helping to provide services to other environs. Examples of the roles of riparian vegetation in assisting with the roles of riparian vegetation in assisting with the movement of energy and nutrients of the system include:

- Show water flow and help stabilise stream banks
- Provide food, shade and habitat for plants and animals;
- Filter sediment, pollutants and nutrients before they enter the stream;
- Valuable indicators of catchment conditions.
- Large contributors to biodiversity, cultural and economic values of Northern Australia.

However because of their productivity, riparian areas are often the focus of activity related to development including grazing, agriculture and tourism subjecting them to disturbances from weeds, feral animals, fire, erosion, over-grazing and impacts on in-stream water quality.

The TRARC method allows for the assessment of riparian vegetation in conjunction with the assessment of impacts by development. Vegetation condition should only inform decision-making when used alongside other information, Therefore TRARC is a visual assessment of the riparian zone using indicators of condition and is designed as a user-friendly for non-specialists (including community groups) and is best suited for savannas streams with a well defined channel and a distinct riparian zone (Dixon et al, 2006). Therefore the TRARC index is derived from 24 indicators grouped into four sub-indicis:

1. Plant cover (cover of vegetation provided by all)
2. Regeneration (amount of native plant regeneration)
3. Weeds (cover of weeds to natives)
4. Erosion (amount of bank erosion)

Also an index of PRESSURE is derived from 6 indicators which help identify the likely cause of change in condition, which includes both anthropogenic factors and natural features that make the riparian zone vulnerable to change (Dixion et al, 2006).

The TRARC method involves the establishment of 3 x 100 m transects with 3 assessment sites within each transect of a 5 m radius (Dixon et al, 20006). Transects were chosen to represent 3 different sections of Berry Creek (up, middle and down streams). This method was used to gain an understanding on stream existing stream condition and impacts of surrounding land use on Berry Creek prior to establishment of monitoring sites and in conjunction with the AusRivas Physical Assessment Tool.

8.6 Collecting and Understanding Historical Data

A scan of historical data was undertaken in August 2009 of data collected by the Department of Natural Resources, Environment and the Arts via HYDSTRA (Oracle Database responsible for storing the Department's water data) and NRETAS Maps. Staff from expertise areas of the Department were also consulted in relation to obtaining historical monitoring data pertaining to Berry Springs and the dolomite aquifer. NRETAS maps assisted with the provision of historical technical reports of the Berry Springs Area and internet searches provided assistance with social history related to the springs.

9. Results

Consequently the key into understanding and then managing the environmental water requirements of GDE's must explore and draw conclusions of the following 4 key factors:

- The nature of ecosystem dependency on groundwater input
- Water requirements of the ecosystem
- Groundwater regime, satisfactory in supplying the water requirements of the ecosystem; and
- The impacts of changes in groundwater regime on ecological processes.

This section will endeavour to analyse historical, field and lab data to draw conclusions of the EWR requirement for Berry Springs and Berry Creek according to the above mentioned key factors and will later dater discuss in details the findings of investigations in Section 8 and provide recommendations for improvements in the understanding of these factors for Berry Springs in Section 9.

9.1 Water Quality

Groundwater is typically measured in terms of Electrical Conductivity (salinity), pH, Temperature, basic chemistry and nutrient content (phosphates and nitrates). In assessing the quality a number of these parameters are important in providing indications in the origins of groundwater. In the case of Berry Springs, parameters such as pH, EC/TDS, Mg, Ca and HCO3 can assist in determining origin of springs from the Berry Springs Dolomite Aquifer. In terms of impacts on ecosystem health the monitoring of nutrient/contaminant concentrations such as heavy metals are vital. Ecosystems and their component species would typically function adequately over certain ranges in water quality. Outside these ranges, the composition and health of attributes becomes important to the ecosystems in circumstances where there is a sustained change in quality or trend away from the natural water quality state.

Temperature data was collected from Northern Territory Government (NTG) gauging stations (1960-2005) and via in-situ field sampling (2008-2009).

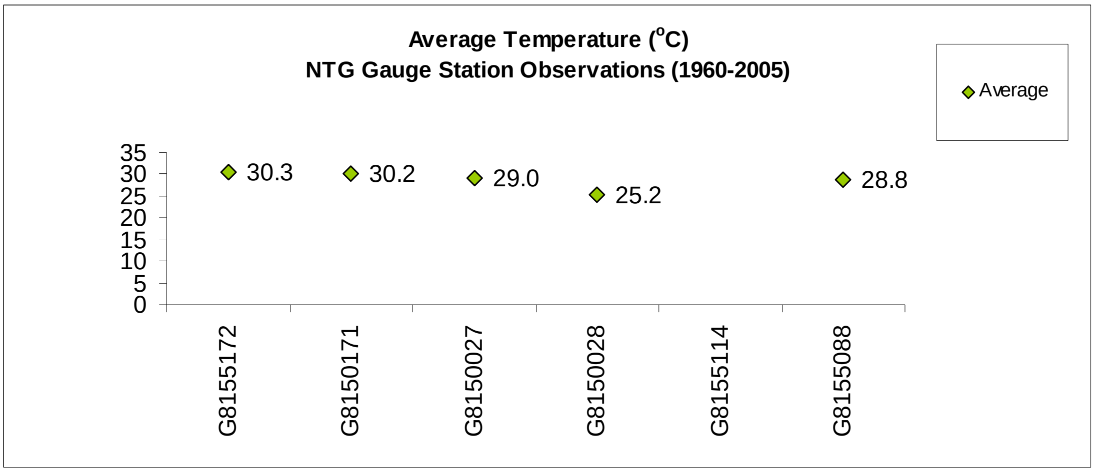


Table 9-1 Average Water Temperatures of NTG Gauging Stations (1960-2009)

Results in NTG Gauging stations showed that average water temperatures over a 45 years period from 1960-2005 did not vary greatly from 25.2-30.3 ^{o}C. Upon initial analysis of this data it could be seen that the length and consistency of records, particularly of those proved for G8150028, varied greatly and were deficient in areas. Therefore in light of this an average temperature of 29 ^{o}C would most accurately represent average water temperatures of NTG gauge station observations and will therefore be used to compare with in-situ field measurements (2008-2009) in water temperatures.

Temperature measurements undertaken during in-situ field sampling in 2008 and 2009 varied from 29.0 to 31.5 ^{o}C as highlighted in figure 8-1. Minimum ground temperatures vary from as little as 11-21 ^{o}C. Maximum ground temperatures vary from 17-26 ^{o}C. Often water temperature has ability to provide an indication of origin by correlating measurements with variations in ground and air temperature fluctuations with changing of seasons. However groundwater temperatures do not generally fluctuate as it is discharged to the surface from deep aquifers where temperatures are not influenced by changes in climate. Therefore constant temperatures represented in groundwater results of this study over a two year period could indicated the presence of groundwater in surface water flows.

Higher pH levels in surface water can indicate the presence of dissolved limestone/dolomite. Typically groundwater, especially due the acidity of soils in the wet dry tropics of Australia is slightly more acidic that surface water. pH levels in bores water is generally characterised by aquifer rock types. In dolomite bores it is not uncommon to find pH levels ranging 6-8 due to the hardness of the water. Data observed in NTG Observation bores (1993-1994) described average pH levels ranging from 6.5-8.1

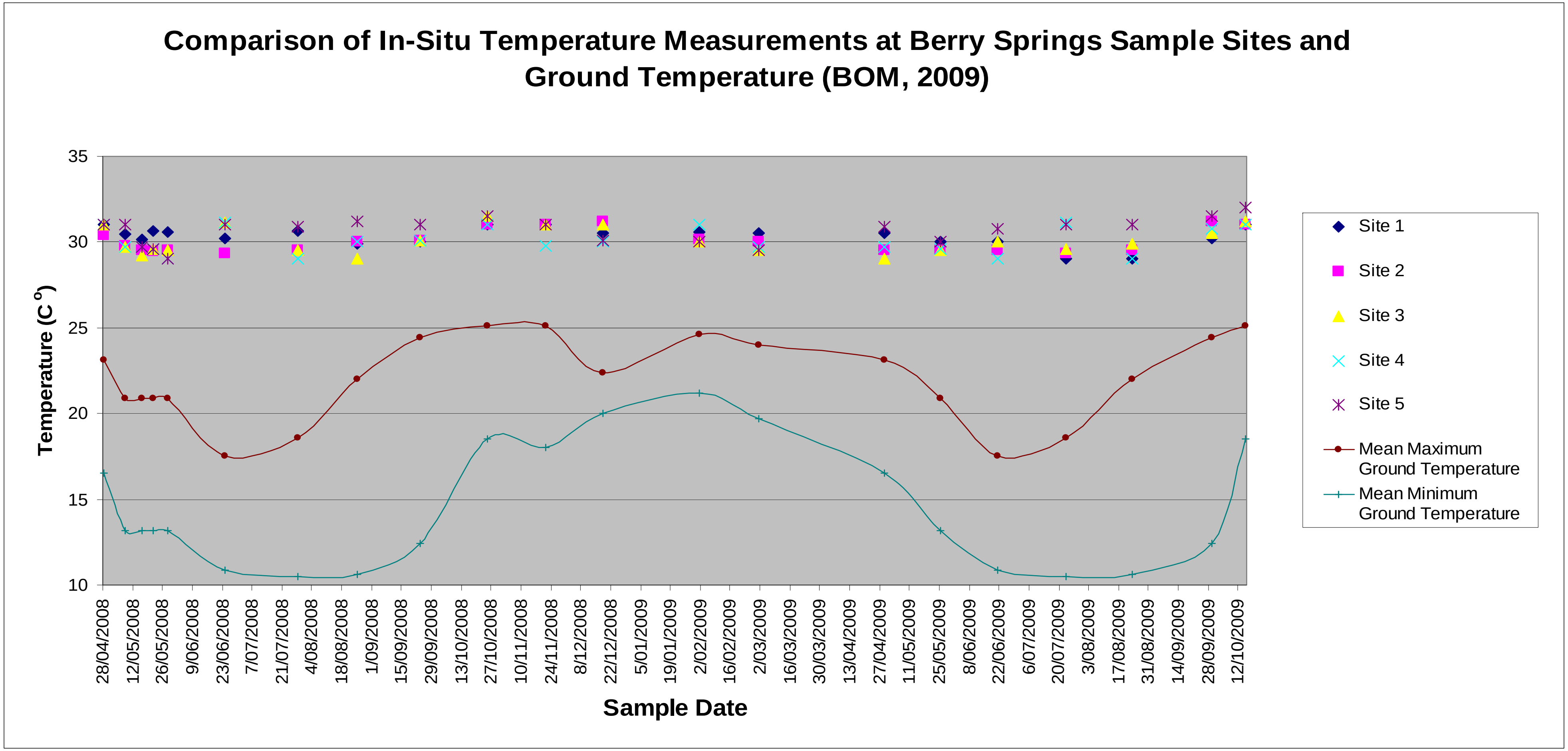


Figure 9-2 Comparison of In-Situ Water Temperature Measurements and Ground Temperature for Samples Sites 1-5 (2008/2009)

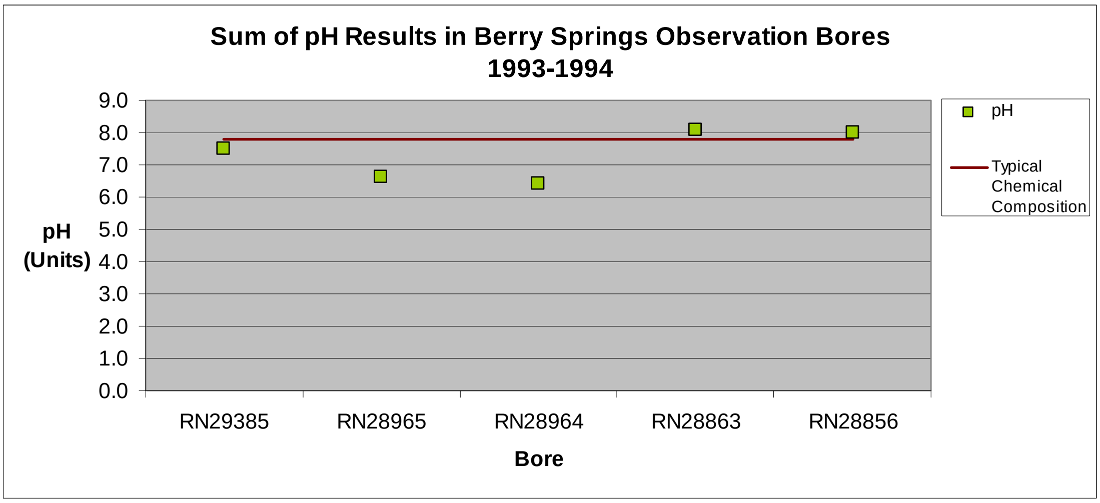


Figure 9-3 Sum of pH Results from Berry Springs Observation Bores

Results from pH level data from lab samples collected in 2008-2009 indicated that pH levels varied from 7.7-8.2 and in-situ field samples undertaken over the same two year period also presented pH levels between 7.0-8.6. Correlations between pH levels found in observation bores and pH levels found in surface water flows at Berry Springs can be made in relation to similar pH ranges that indicate that surface water spring flows originate from the Berry Springs Dolomite Aquifer.

Water chemistry results of bicarbonate (HCO3) are elevated in both NTG Observation Bore Data and lab samples. Bicarbonate is a weak alkali. Alkali's have a pH level of 8-14 depending on strength. High bicarbonate levels can be directly linked to pH levels observed in bores and surface water flow at Berry Springs.

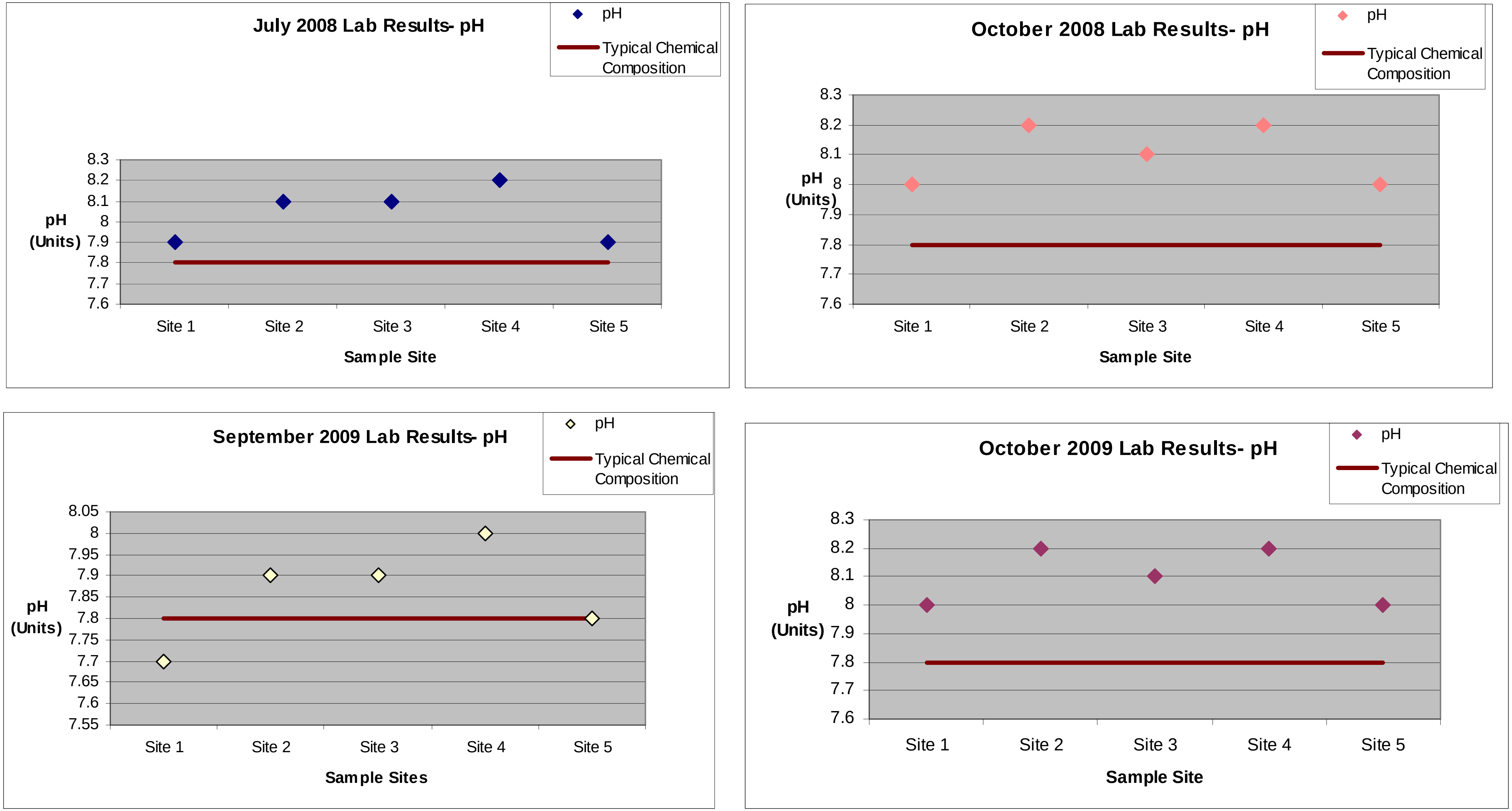


Figure 9-4 2008/2009 Lab Results, Berry Springs Sample Sites 1-5.

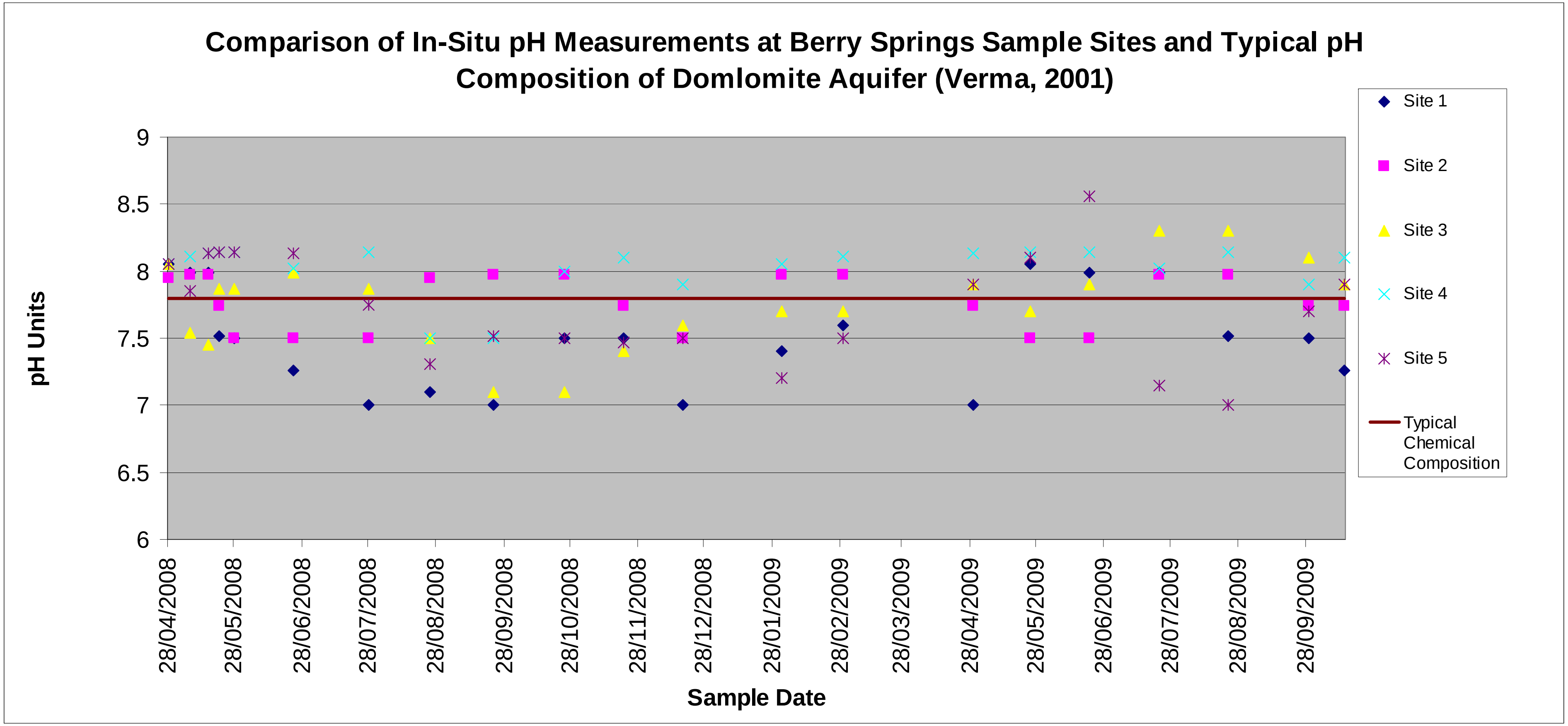


Figure 9-5 Comparison of In-Situ pH Measurements at Berry Springs Sample Sites 1-5.

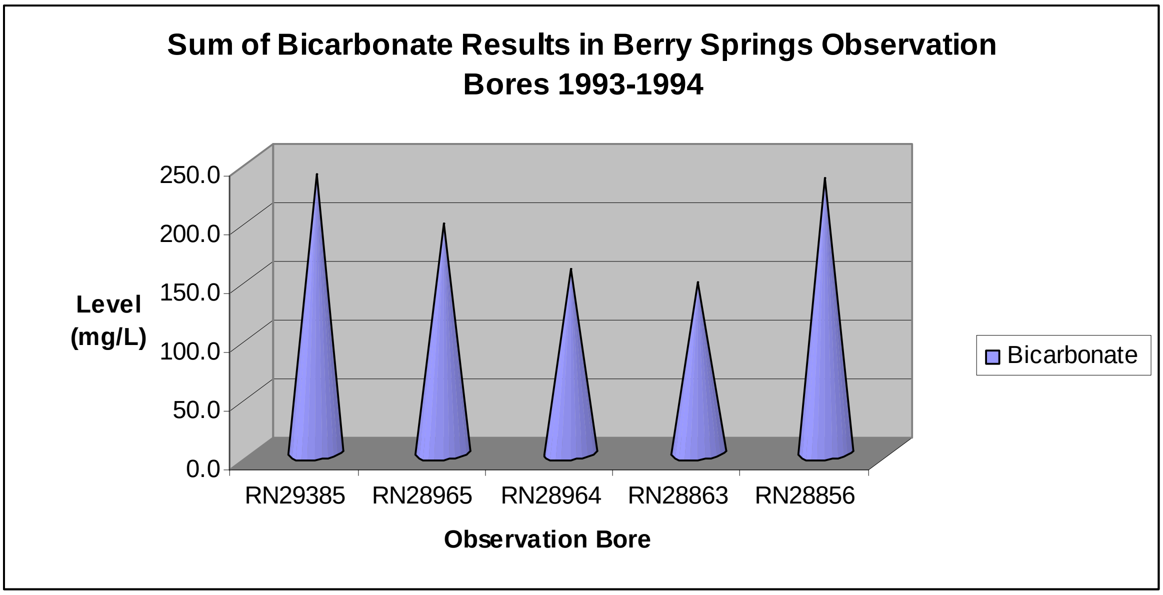


Figure 9-6 Sum of Bicarbonate in Berry Springs Observation Bores (1993-1994)

Carbonate rocks are sedimentary rocks containing more than 50% carbonate minerals, usually represented as calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$). Water derived from dolomite aquifers would expect to display high levels of magnesium (Mg) and calcium (Ca). Water chemistry results from NTG Observation Bores and lab samples from surface water monitoring sites show consistent levels of Mg and Ca at sampling sites are listed in Table 10-1. Mg and Ca levels had a slight increase during the months of October 2008 and October 2009 and attributed to a cease in influence from surface runoff experienced at the end of the wet season to total reliance of groundwater during the dry season.

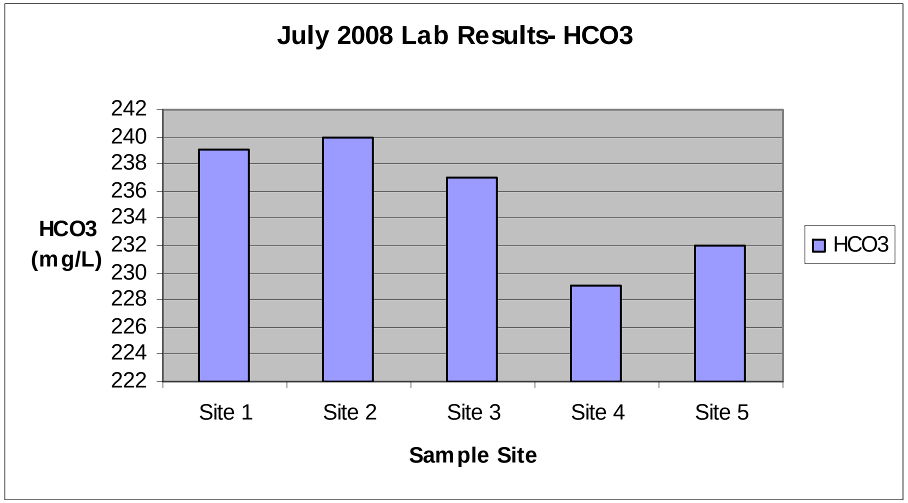
Sample Site	Mg	Ca	Date
Site 1	29	27	24/07/2008
Site 2	29	29	24/07/2008
Site 3	29	28	24/07/2008
Site 4	28	28	24/07/2008
Site 5	28	27	24/07/2008

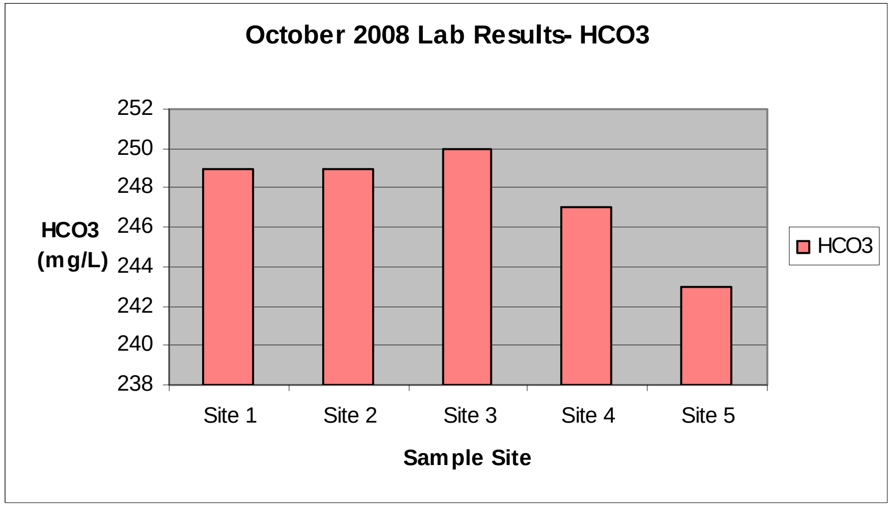
Sample Site	Mg	Ca	Date
Site 1	32	29	24/10/2008
Site 2	32	29	24/10/2008
Site 3	34	32	24/10/2008
Site 4	32	29	24/10/2008
Site 5	31	29	24/10/2008

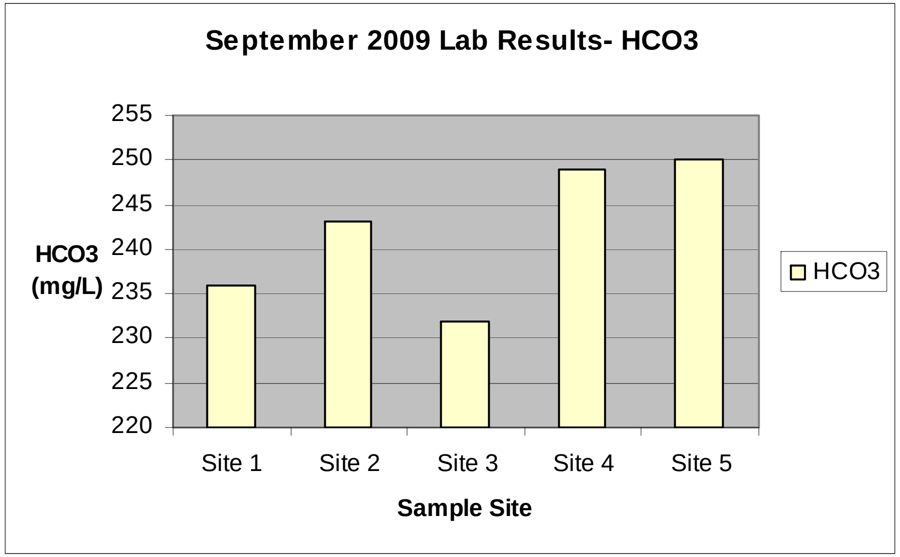
Sample Site	Mg	Ca	Date
Site 1	31	29	29/09/2009
Site 2	30	29	29/09/2009
Site 3	31	29	29/09/2009
Site 4	31	29	29/09/2009
Site 5	30	29	29/09/2009

Sample Site	Mg	Ca	Date
Site 1	32	29	24/10/2009
Site 2	32	29	24/10/2009
Site 3	34	32	24/10/2009
Site 4	32	29	24/10/2009
Site 5	31	29	24/10/2009

Table 9-7 Magnesium and Calcium Concentrations in Lab Samples from Sites 1-5.







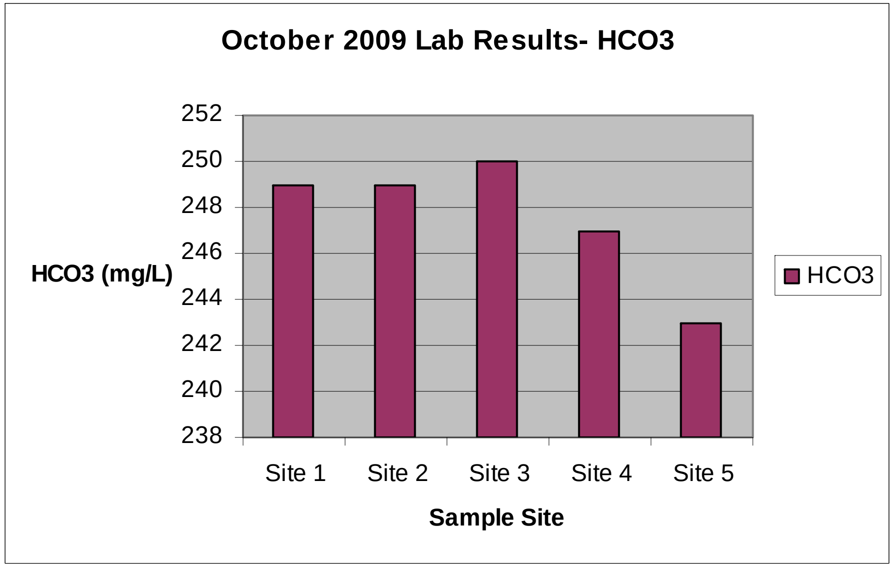


Figure 9.8Lab Results of 2008/2009 for Berry Springs Sample Sites 1-5

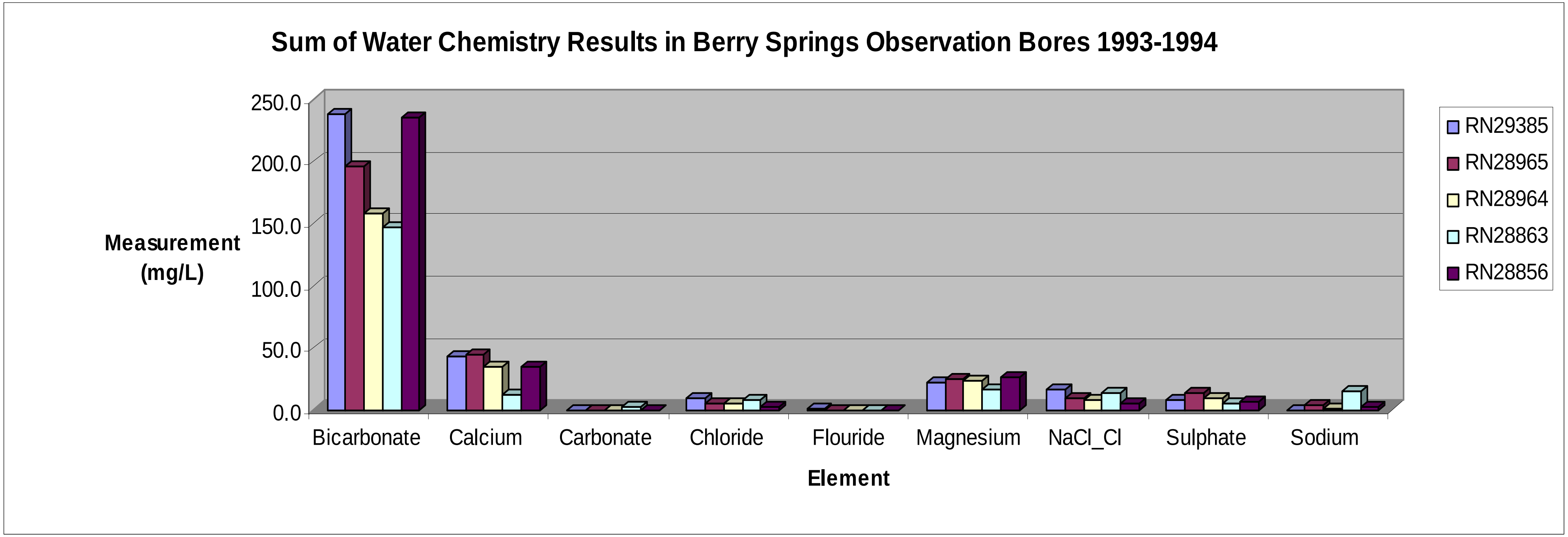


Figure 9-9 Sum of Water Chemistry Results in Berry Springs Observations Bores, 1993-1994.

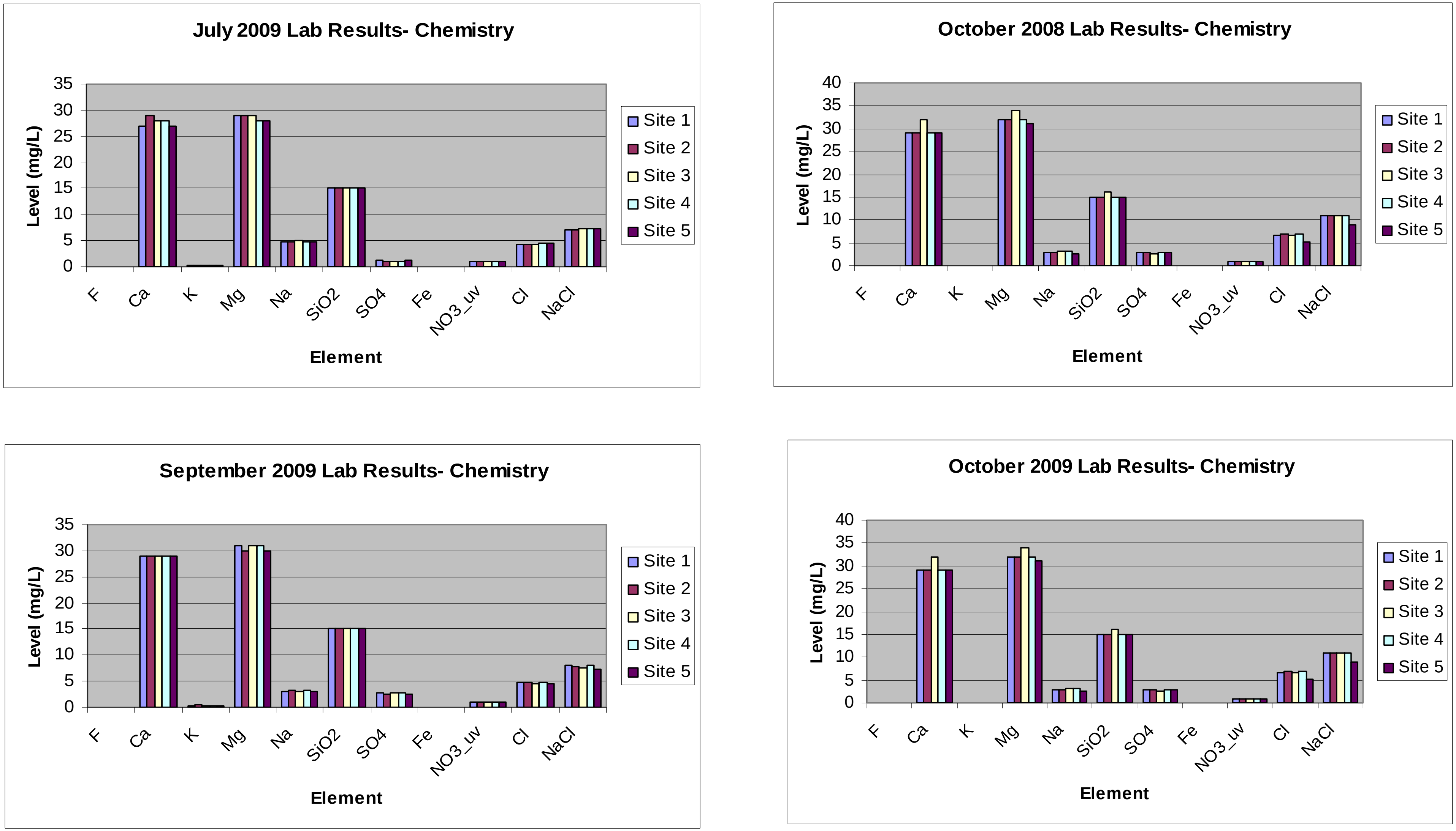


Figure 9-10 Chemistry Lab Samples for 2008/2009 from Berry Springs Sample Sites 1-5

Average TDS results in Berry springs observation bores varies from 90 mg/L to 250 mg/L in four out of five bores sampled in 1993-1994. Results in the fifth bore, RN28965, shows an average TDS of 730 mg/L. A TDS sample reading taken on the 22/10/1993 showed TDS of 2,400 mg/L, therefore raising the average TDS results shown in Figure 9-11- . A reading this high could be attributed to human error at time of sampling or impact from direct point source pollution. Average TDS readings as low as 90 mg/L measured in 2 bores could be a result of location and drilling depth, In the circumstances of RN28964, Drilling depth of 60 m and groundwater contact at 36-42 m, due to relatively shallow depths could be less weathered and in conjunction with residence time of water due to topographic low and proximity to spring discharge points could provide for less exposure time for contact between acidic water, rock and substrate (NRETAS MAPS, 2009). Bore RN could simply display lower TDS values due to location of drilling in the Wildman Siltstone (NRETAS MAPS, 2009).

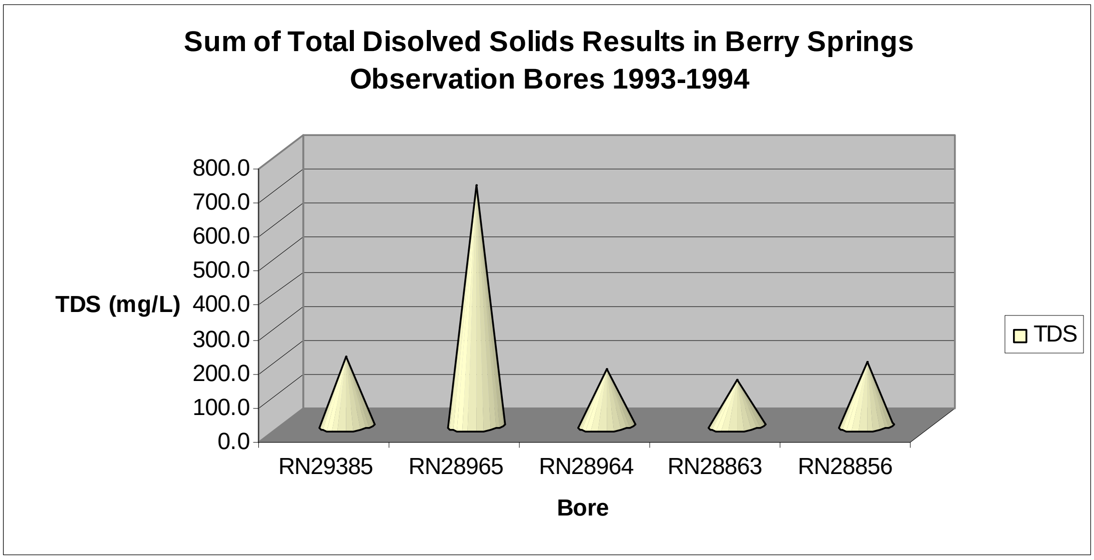
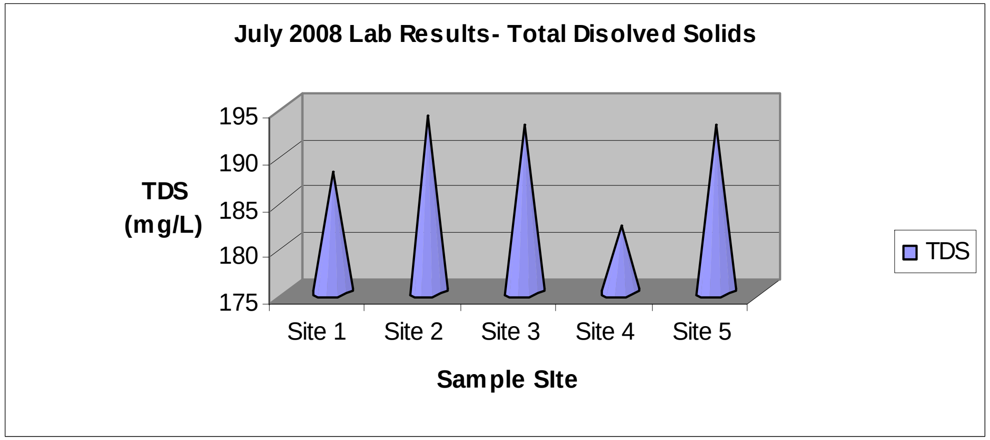
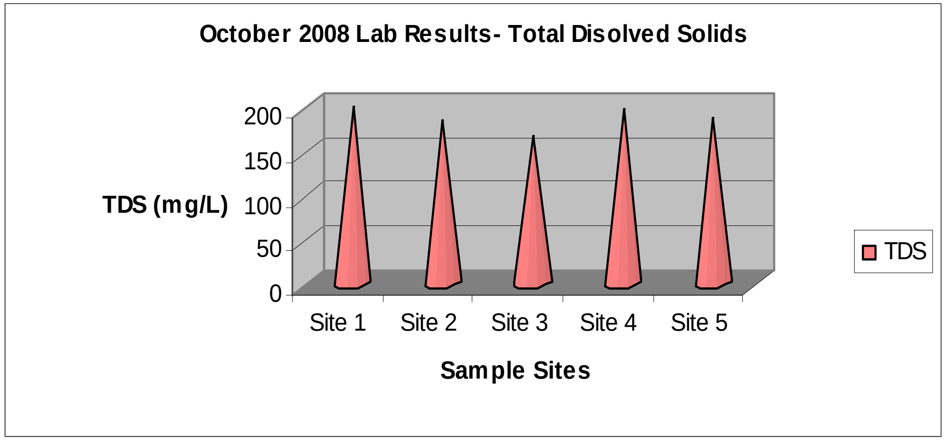
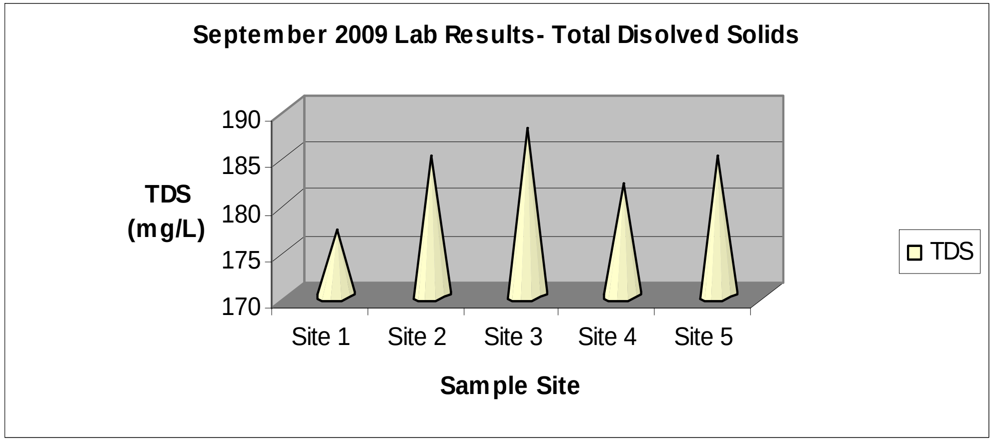


Figure 9-11 Sum of TDS Results in Berry Springs Observation Bores (1993/1994)







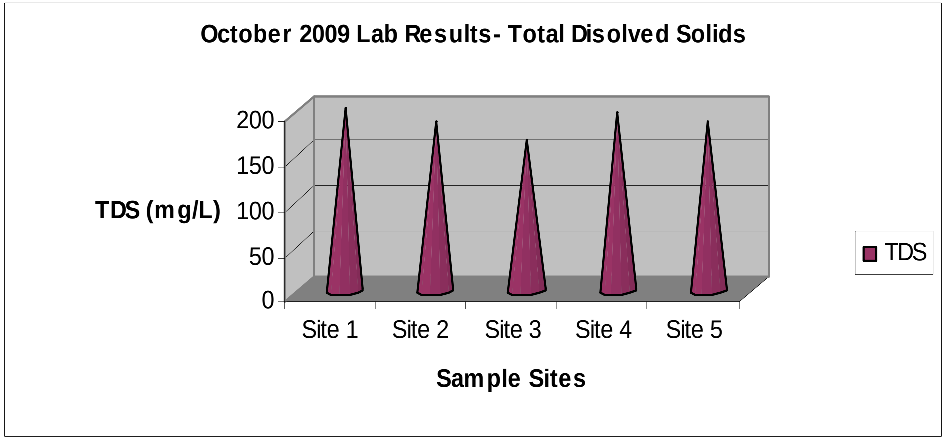


Figure 9-12 2008/2009 Lab Results for TDS from Berry Springs Sample Sites 1-5.

TDS results from lab samples measured at Berry Springs monitoring sites in 2008/2009 did not vary greatly between samples measured in October 2008 and samples taken in October 2009 from 150-200 mg/L. Moderate variations could be noted in July 2009 samples of between 181-194 mg/L and in September 2009 of between 176 mg/L -186 mg/L. Moderate variations in lab results could be attributed to variations in the months sampled with more concentrated TDS results in October influenced by peak low season flows sustained by groundwater from the Berry Springs Dolomite aquifer.

Measuring Electrical Conductivity (EC) is different to measuring TDS, as EC is used to measure the electrical conductance of water. Total dissolved solids measures the amount of ions in water, while conductivity measures an ion's ability to do conduct electricity. With increased ion content in the water, higher the electron flow. Generally there is a strong correlation between conductivity and TDS. Conductivity is only an approximate predictor of TDS.

Average Electrical Conductivity (uS/cm) results displayed in NTG Gauge Station observations (1960-2005) ranges from 83- 414 uS/cm. Lowest recorded readings were present in G8150028, of which was established to monitor overland flow during the wet season and therefore observations at this site are representative of surface water runoff independent of groundwater influence providing an explanation of lower readings of TDS. The highest TDS readings were captured in station G8150027 at 414 Us/cm. G8150027 is located furthest downstream of all gauging stations and study monitoring sites within saltwater reaches of Berry Creek, provide and explanation of significantly higher TDS readings in comparison to average TDS readings between 255-368 uS/cm in stations G8155114, G8150171 and G8155172. Results of 171 uS/cm from station G8150028 could be attributed to the location of the gauging station in the upper reached of Berry Creek in an area outside influence from groundwater flows. This station makes for a good comparison between TDS in wet season surface water runoff with TDS in groundwater flows from stations G8155114, G8155172 and G8150171.

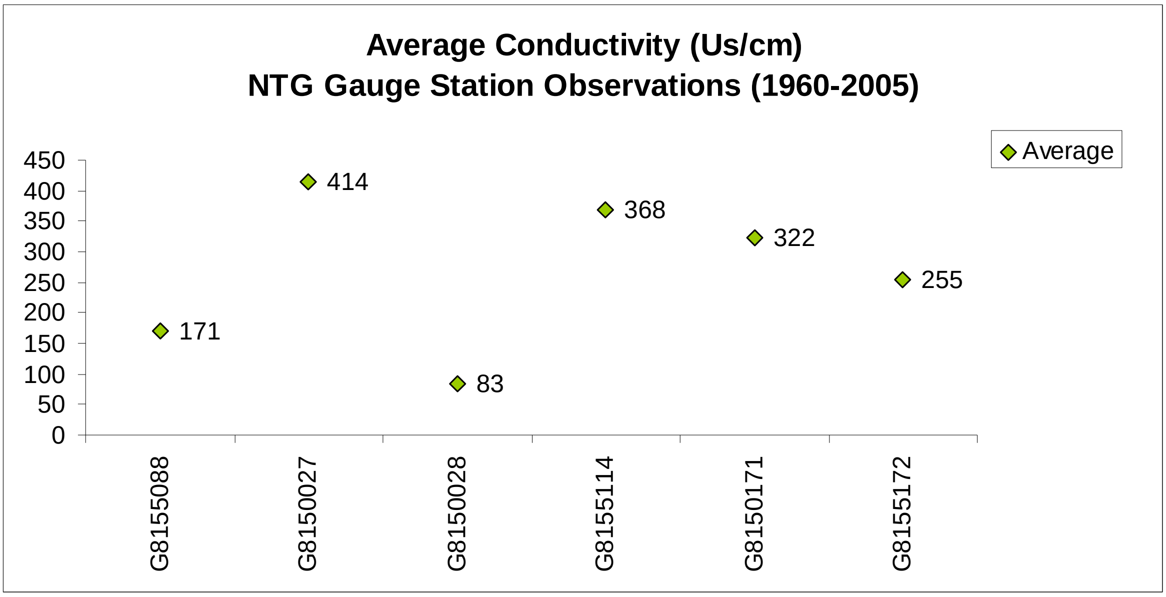


Figure 9-13 Average Conductivity Results for NTG Gauge Stations (1960-2005)

Electrical Conductivity (uS/cm) results in observation bores varied between 250 uS/cm to 425 uS/cm. The lowest result was recorded in RN28863, in a bore located further most from Berry Creek in the higher reaches of the catchment. Significance of this result could be attributed to the location of the bore on the edge of the contact between the Berry Springs Dolomite and shales/siltstones of the Wildman Siltstone formations. It is likely that water in this bore is influenced more greatly from minerals in the Wildman Siltstone formation than that of the dolomite found in the Berry Springs Dolomite formation as indicated in bore log RN28863 (NRETA MAPS, 2009).

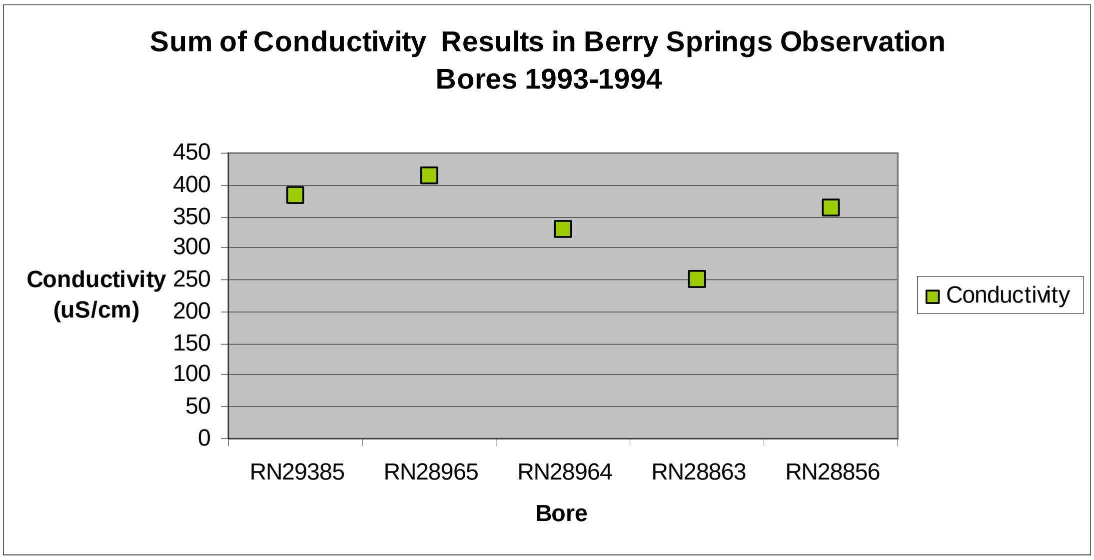
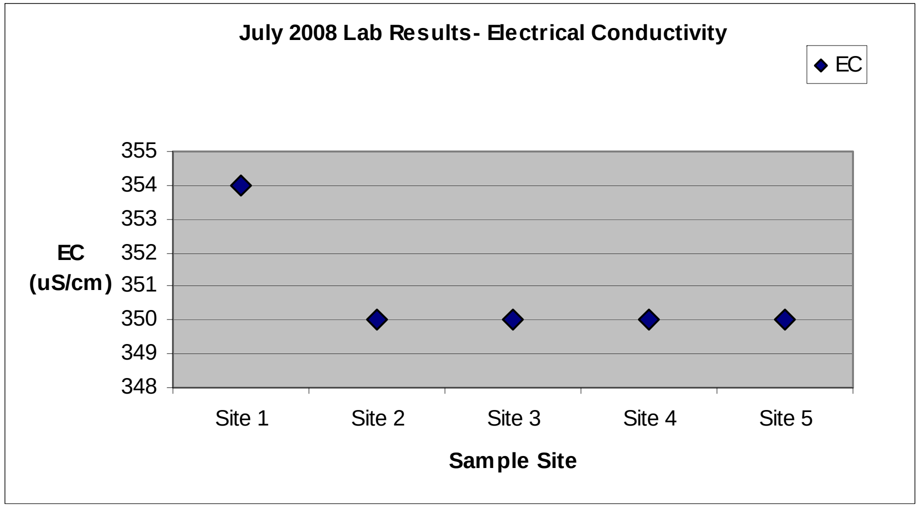
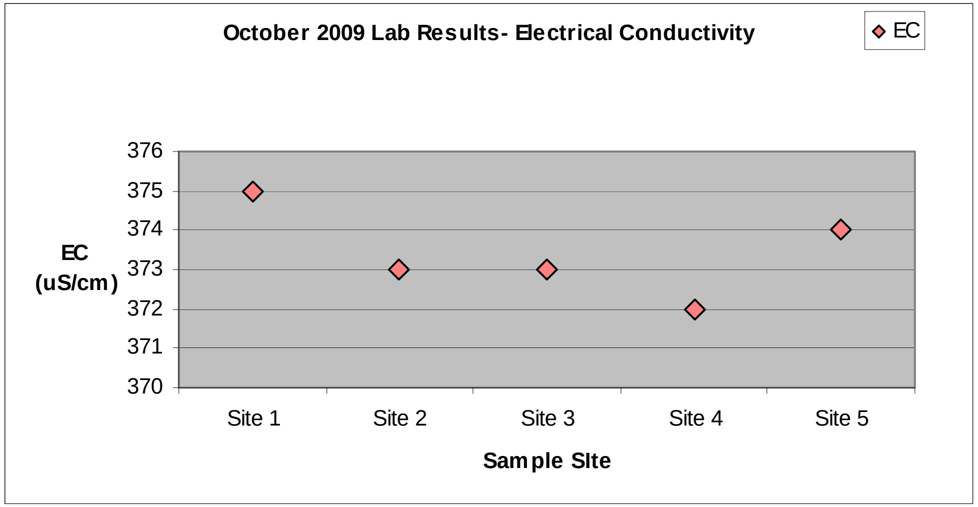


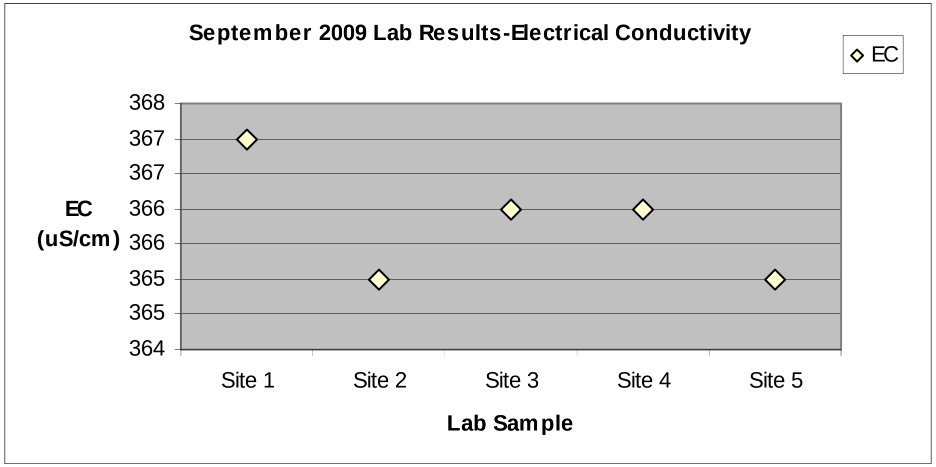
Figure 9-14 Sum of Conductivity Results in Berry Springs Observation Bores (1993/1994)

Electrical Conductivity (uS/cm) in lab samples taken from sample sites 1-5 in 2008/2009 coincide with results measured in gauging stations and observation bores influenced by groundwater in the Berry Springs Dolomite aquifer. EC from sample sites measure in July 2008 show that EC does not vary greatly from 350-354 uS/cm, increasing slightly from 350-354 uS/cm in results from October 2008. Similarly results presented in samples tested in September 2009 vary between 365-367 uS/cm, increasing slightly from 372-375 uS/cm. Results are represented in the figures below . Both sets of results, consistent with results in gauging stations and observation bores show definite signs of groundwater influence during periods of lowest flow.

In-situ field testing varies moderately over the two year period with minimum EC of 310 uS/cm (January 2009) occurring during the wet season (period of highest surface runoff) and a maximum EC of 382 uS/cm occurring during the dry season (October 2008) during peak of lowest flow.







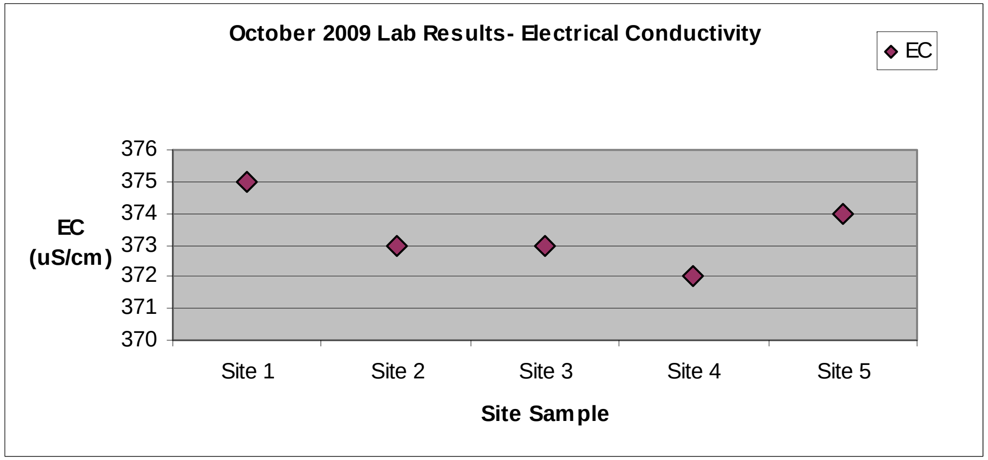


Figure 9-15 2008/2009 Lab Results for Electrical Conductivity form Berry Springs Sampling Sites 1-5.

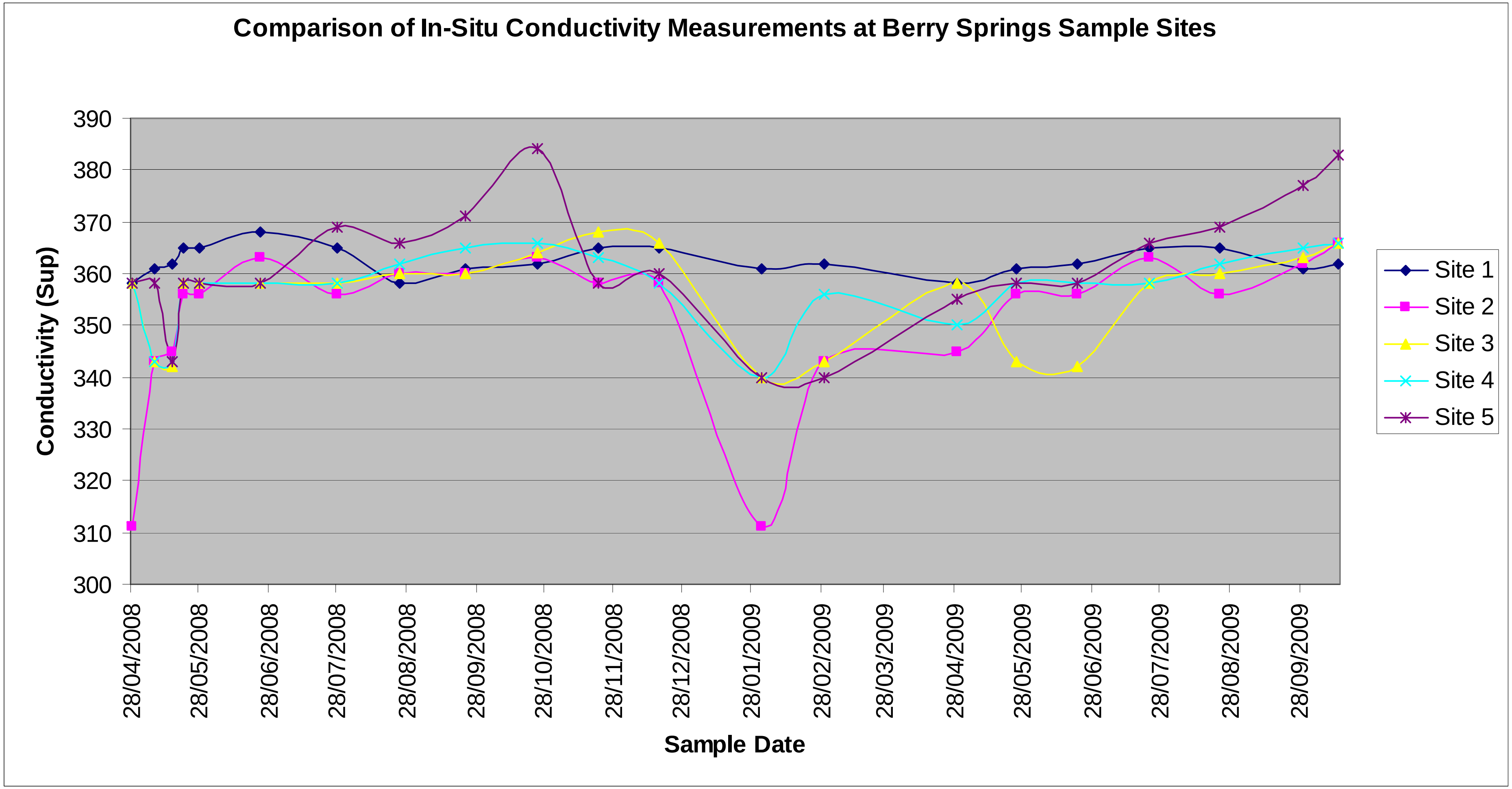


Figure 9-16 Comparison of In-Situ Conductivity Measurements at Berry Springs Sample Sites 1-5 (2008-2009)

9.2 Physical Analysis of Groundwater Flow

The volumetric flow rate in fluid dynamics and hydrometry, (also known as volume flow rate or rate of fluid flow) is the volume of fluid which passes through a given surface per unit time (for example cubic meters per second [m3 s-1] in SI units, or cubic feet per second [cu ft/s]). Volumetric flow rate should not be confused with volumetric flux, as defined by Darcy's law and represented by the units of m3/(m2 s). The integration of a flux over an area gives the volumetric flow rate. Volumetric flow can be used to determine flow rates within rivers, creeks and stream.

Groundwater recharge is an important process for sustainable groundwater management. Groundwater recharge can be monitored by assessing Standing Water levels in bores. In Northern Australia, for example, Berry Springs, precipitation during the wet season is often much higher than precipitation during the dry season and so the groundwater storage is not fully recharged during the dry. Consequently, the water table is lower in the dry season yearly. This disparity between the level of the wet season and dry season water table is known as the zone of intermittent saturation, wherein the water table will fluctuate in response to climatic conditions.

Volumetric flow rates were measured during the 2008/2009 at 3 monitoring sites (Sites 1, 2 & 4) to gain an understanding of volumetric discharge from spring areas through the Berry Creek System. Intentions for the remaining 2 sites (Sites 3 & 4) were aborted due to safety issues in collecting measurements at the sites. These measurements where correlated with monthly rainfall and evaporation data for 2008/2009, revealing a relationship in the decrease in rainfall with the decrease of surface water flow from April to October in both years. Standing Water Level data was also correlated with rainfall for Berry Springs Observation Bores RN28964, RN289385, RN28965, RN28863, RN28856 and showed a distinctive relationship between rainfall and standing water level identical to that of the relationship between volumetric flow and rainfall.

During the months from June to October little or no rainfall occurred, however flow (although significantly reduced) was still present at flow rates of 0.15-0.2 m3/s, even when evaporation exceeds participation by 200%. 2008/2009 volumetric flow rates were also correlated with standing water level data in bore RN28964 as the location of this bore is within close proximity to the spring and flow monitoring sites. Correlations between standing water levels of RN28964 and flow data from Sites 1 & 5 show consistencies in the decrease of flows in conjunction with a decrease in standing water level, showing that rainfall directly influences Standing Water Levels in RN28964 and flows with Berry Creek (and associated springs).

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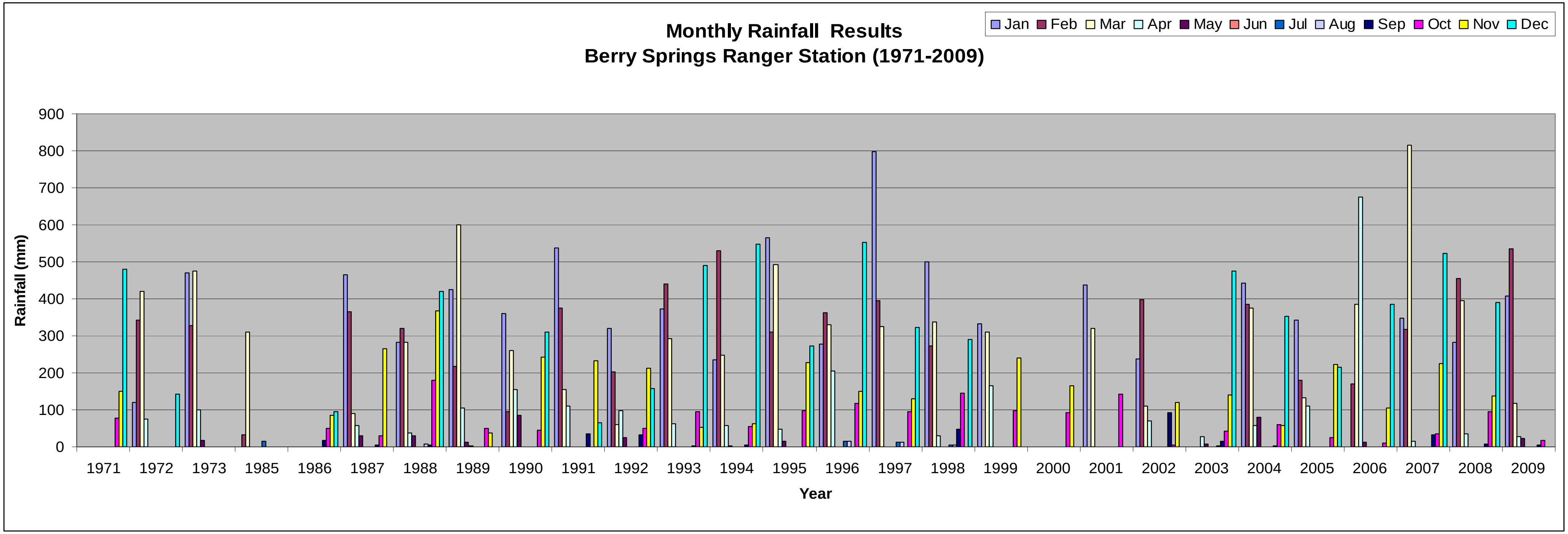


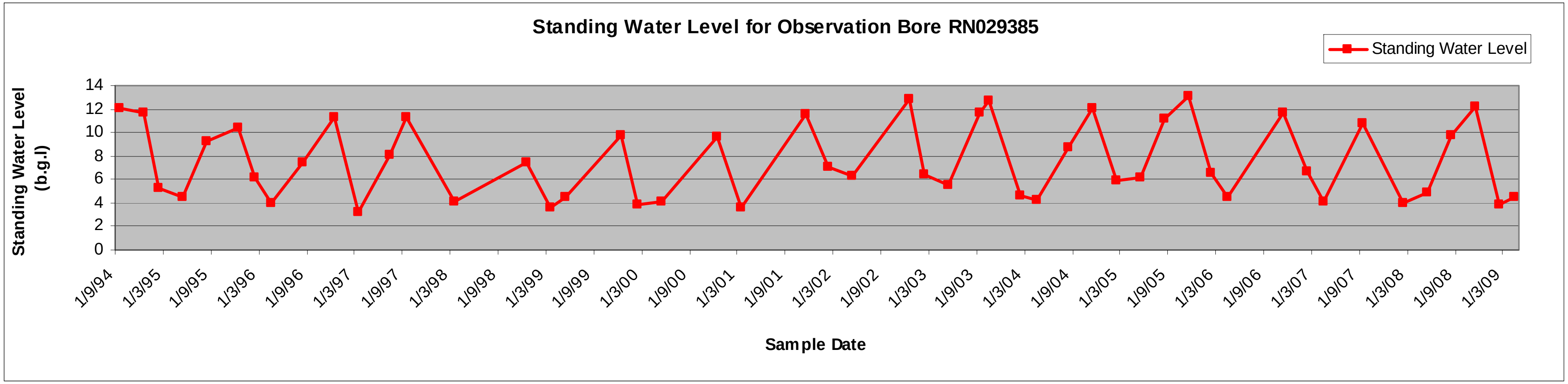
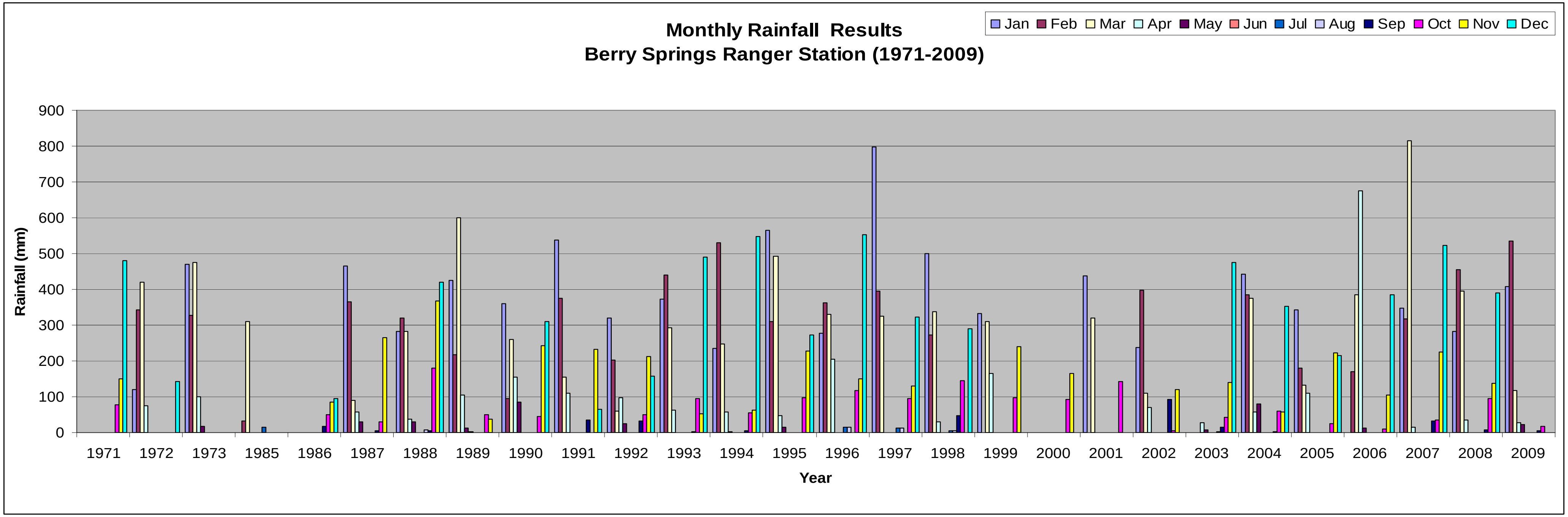


Figure 9-17 Monthly Rainfall Results, Berry Springs Ranger Station (1971-2009) and Standing Water Levels for RN029385



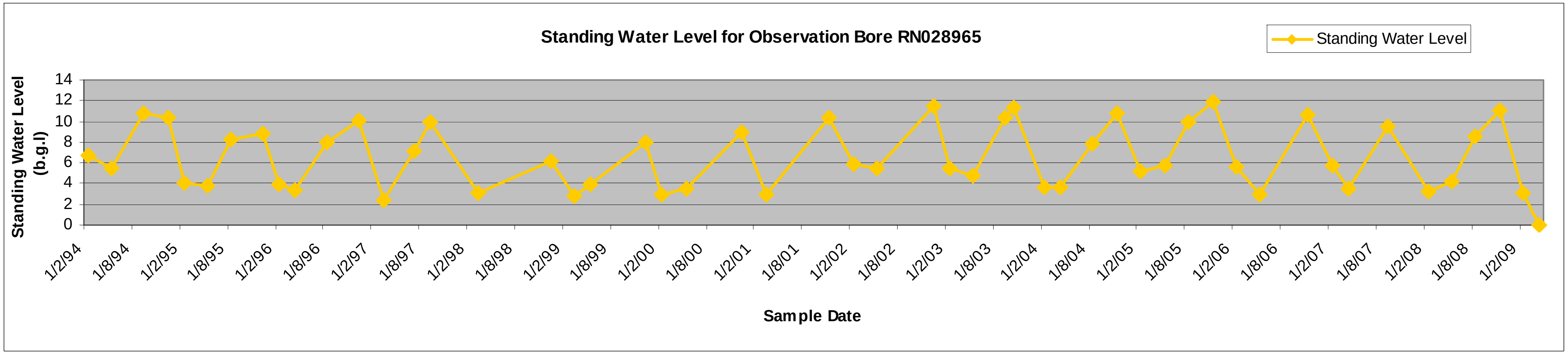
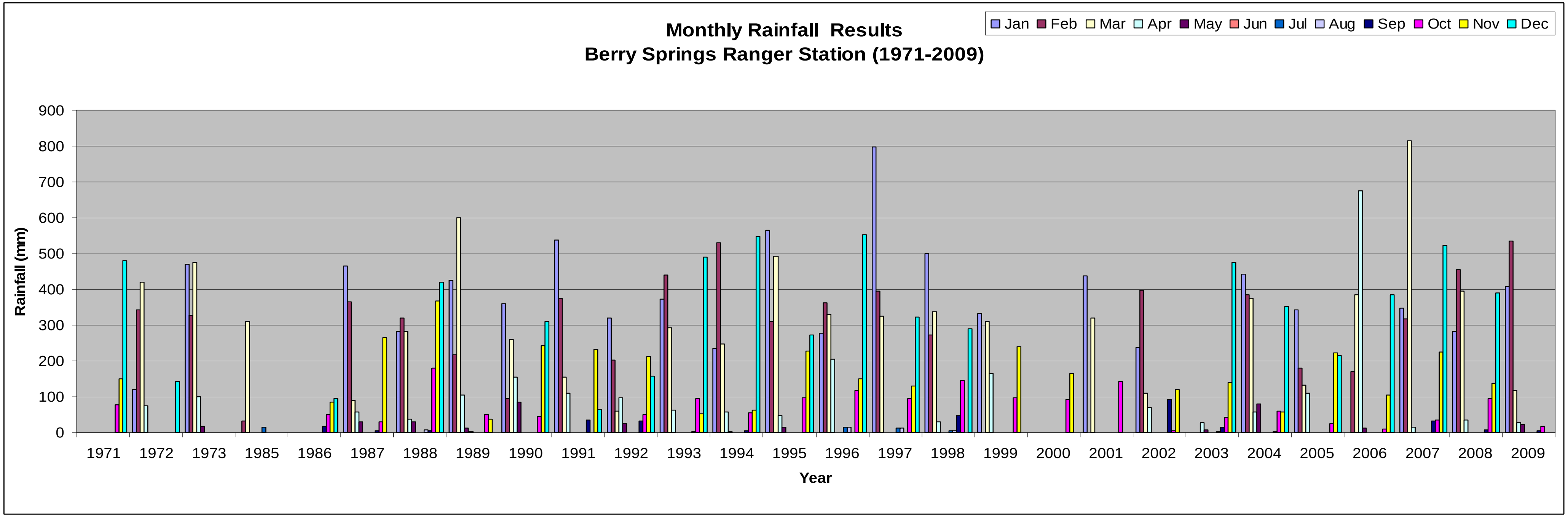


Figure 9-18 Monthly Rainfall Results, Berry Springs Ranger Station (1971-2009) and Standing Water Levels for RN028965



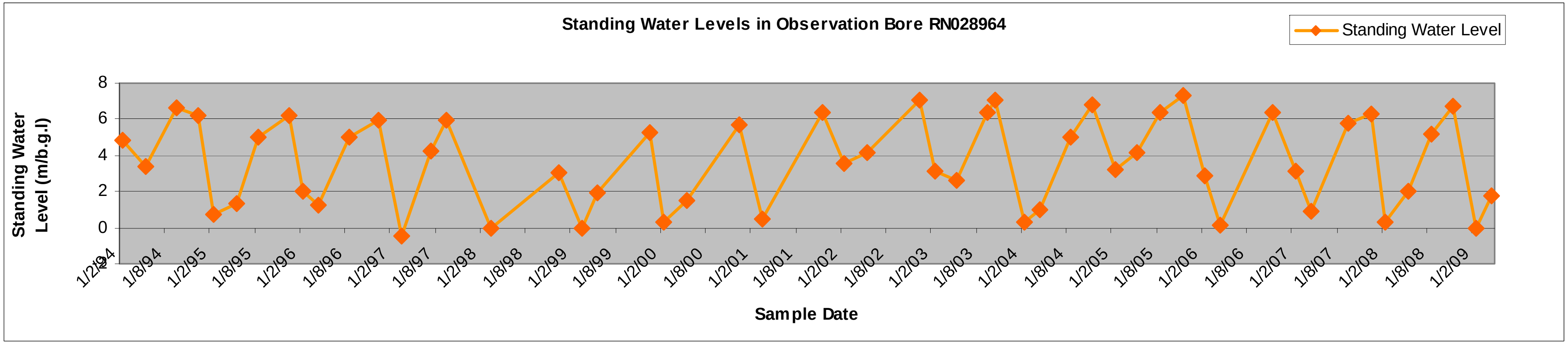
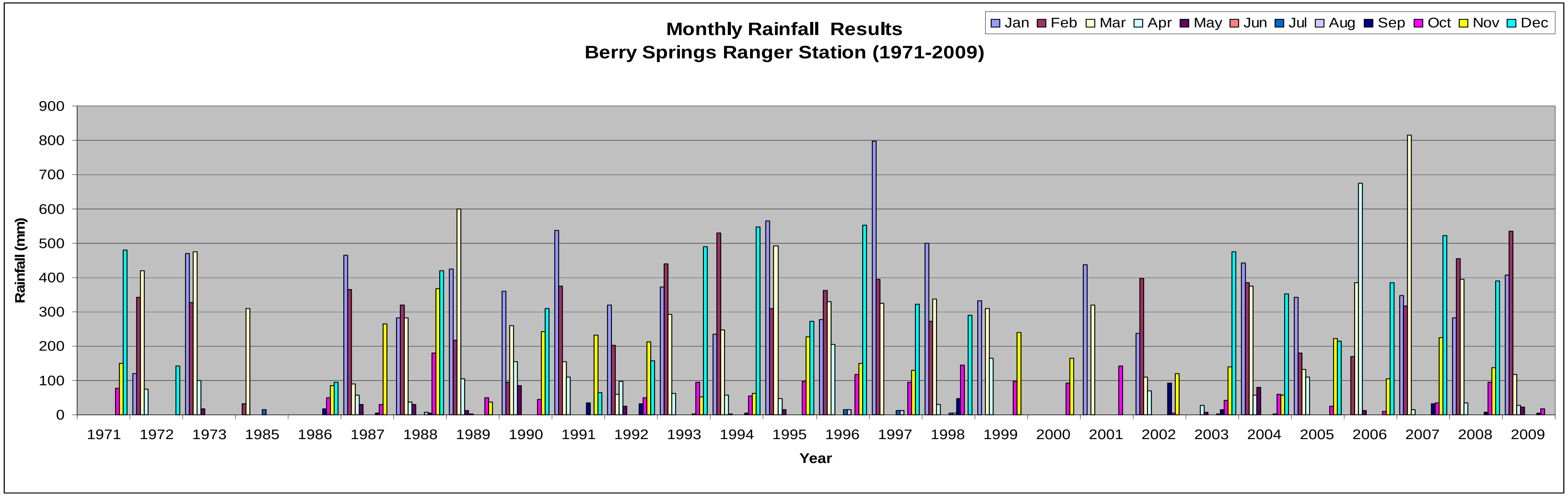


Figure 9-19 Monthly Rainfall Results, Berry Springs Ranger Station (1971-2009) and Standing Water Levels for RN028964



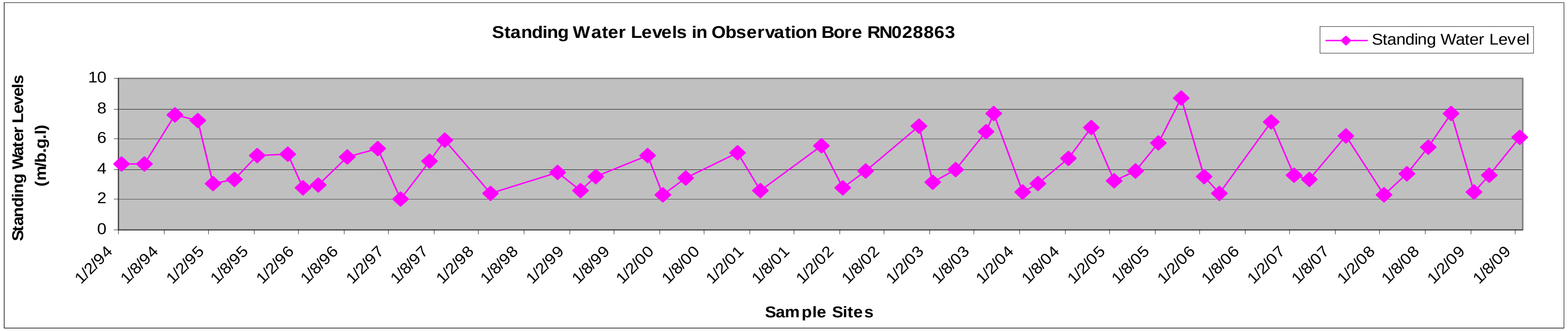
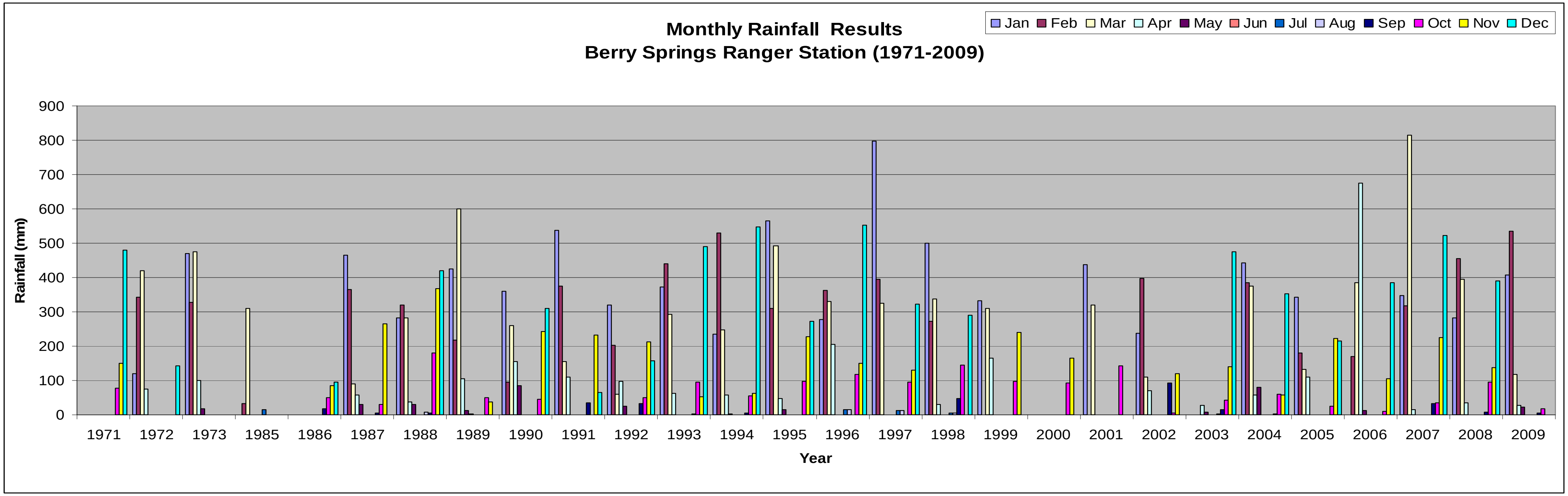


Figure 9-20 Monthly Rainfall Results, Berry Springs Ranger Station (1971-2009) and Standing Water Levels for RN028863



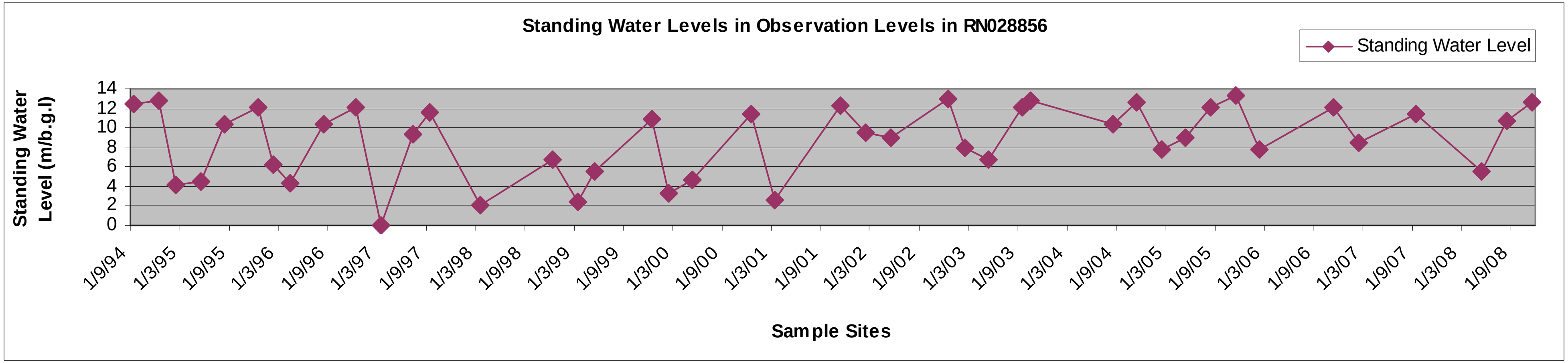
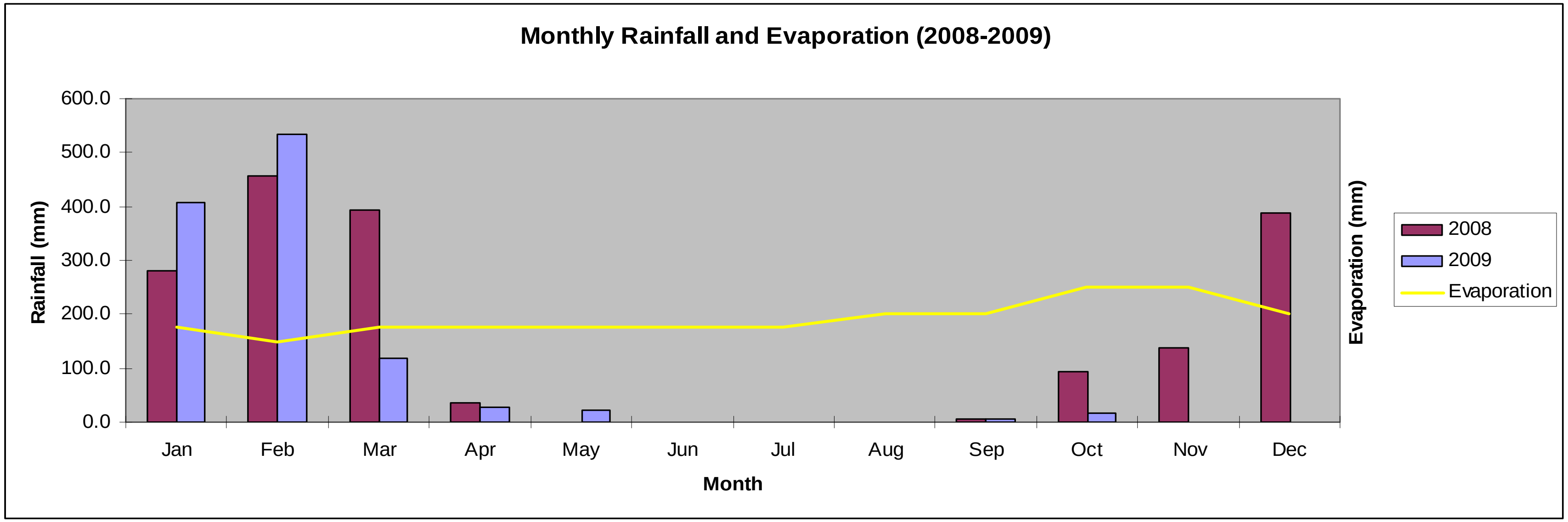


Figure 9-21 Monthly Rainfall Results, Berry Springs Ranger Station (1971-2009) and Standing Water Levels for RN028856



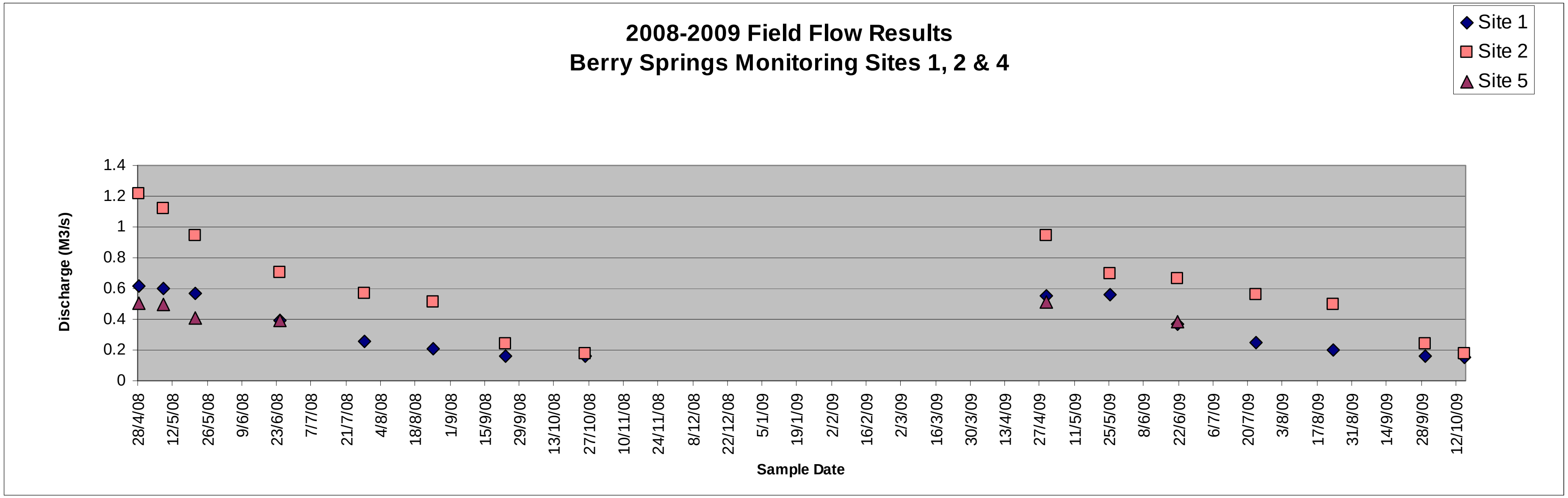
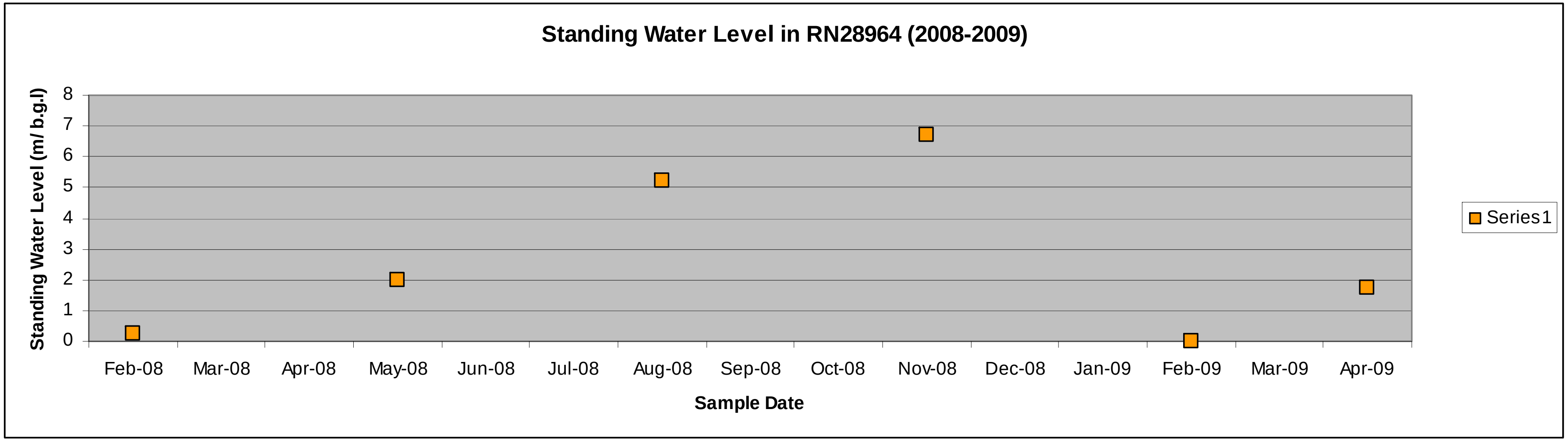


Figure 9-22 Monthly Rainfall and Evaporation and Field Flow Results for Berry Springs Sites 1,2 & 4 (2008-2009)



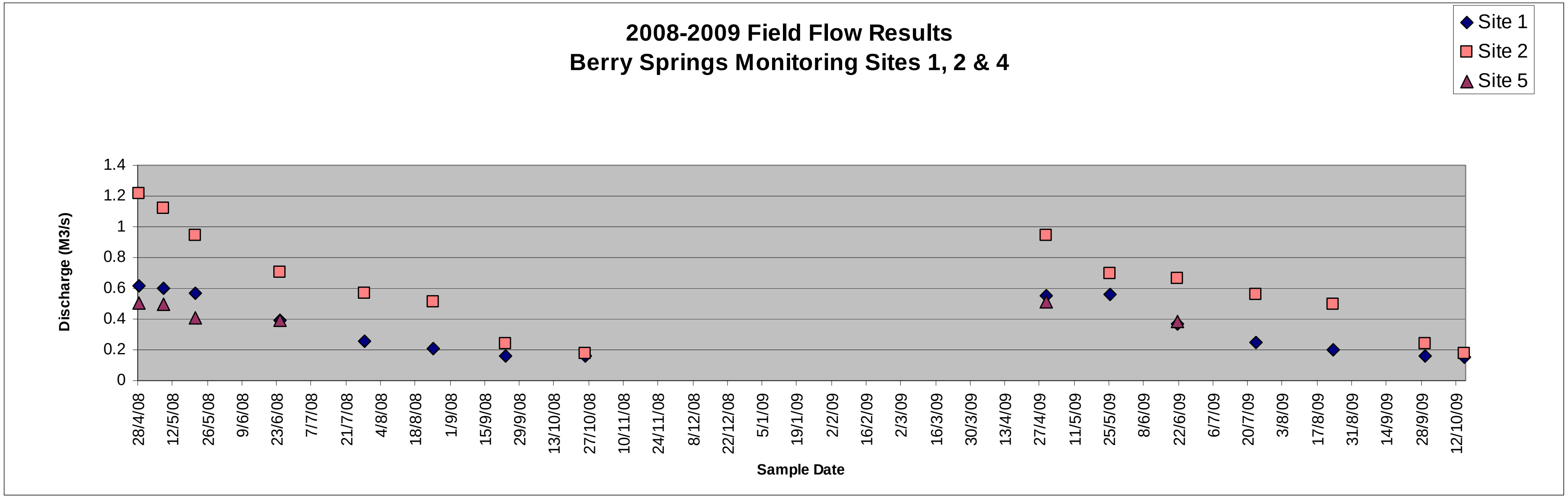


Figure 9-23 Standing Water Levels in RN28962 and Field Flow Results for Berry Springs Sites 1,2 & 4 (2008-2009)

10. Discussion

Little is known about recharge rates of aquifers in Northern Australia. Factors such as climate variability, strata, land use and extraction rates vary greatly between systems, which will in turn effect recharge rates. Planning, policy and management of systems as well as community values will also determine principal uses of water within a region and the priorities placed on a resource and associated systems such as GDE's.

The dependency of ecosystems on groundwater is based on one or more basic attributes (SKM, 2001);

1. Flow of flux- the rate and volume of groundwater supply
2. Level- for unconfined aquifers and the depth below surface of the water table;
3. Pressure- for confined aquifers, the potentiometric head of the aquifer and its expression in groundwater discharge areas; and
4. Quality- the chemical quality of groundwater encompassing pH, salinity and/or other potential constituents, including nutrients and contaminants.

The response of ecosystems to changes in attributes can vary. Some responses may not be witnessed in the short term and effects may be unsalvageable by the time this is recognised. The threshold responses in some cases are immediate and critical. For example mound spring communities supported by ground waters of the Great Artesian Basin (GAB) rely upon pressure to assist in surface discharge at the spring. If over extraction was to occur and groundwater levels would fall, this would have consequences on the vegetation and fauna that are reliant upon the springs to survive.

Eamus (2006) states that ecosystems are dynamic in nature and are continually changing in response to natural processes; however an accelerated rate of change may be induced by altered water regimes. Before water allocation provisions for the environment can be implemented within a planning region, the environmental, economic and social water values must be considered and trade-offs within regions with varying priorities may be proposed to protect values.

Until the early 1970's, the management of water resources in Australia was predominantly concerned with the assessment, development and harnessing of new water resources for irrigation, urban, industrial and domestic water supply (Eamus, 2006). Consequently water allocation for the environment was not priority and excessive and unsympathetic abstraction of freshwater, particularly groundwater, occurred throughout Australia. It wasn't until 1994 that he Council of Australian Governments (COAG) endorsed reforms to achieve a national sustainable water industry which included allocations for the environment and greater environmental accountability of water resources (Eamus, 2006).

Sustainable water use was again on the political agenda in 1996 when the National Principals for the Provision of Water for Ecosystems were produced by the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the Australia and New Zealand Environment and Conservation Council (ANZECC) to provide the basis for ecological water requirements (EWR's). The guidelines, which are still present and are reviewed regularly to comply with changes in legislation, were developed to propose the extent of scientific information necessary to provide water resource managers with the ability to determine water requirements necessary to sustain or restore ecological processes and the biodiversity of GDE's. Environmental Water Provisions (EWP) were defined as waters that would be allocated after consideration of the social, economical and minimum ecological water requirements and would largely be dependent upon the relative importance placed on the protection of an ecosystem, by the community, in comparison to more human centred water uses (SKM, 2001).

10.1 Environmental Water Requirements

If groundwater management systems, policy and legislation are to appropriately consider protection and conservation of groundwater dependent ecosystems; they will inherently need to be informed by a comprehensive understanding of the nature of the dependency and water requirements of the ecosystem; the groundwater regime required to fulfil the dependency and the perceived and/or actual impacts of change in key groundwater attributes on that system.

The primary step in the process of allocating groundwater to meet the environmental needs of dependent ecosystems is to identify those ecosystems and secondly conducting a detailed analysis of the nature of that dependency. Evidently some GDE's can be identified by undertaking a preliminary field survey, undertaking a detailed desktop analysis and undertaking monitoring in data deficient areas to gain a better understanding of ecosystem behaviour, much of which has been undertaken and detailed in Sections 1-7 of this report.

Environmental water requirements of groundwater dependent ecosystems, as previously mentioned should be specified in terms of four basic groundwater attributes- flux, level, pressure and quality (SKM, 2001). Determination of the environmental water requirement requires an understanding of the interactions between these attributes and the dependent elements of a particular ecosystem and the way in which this varies in time.

If we were to consider the attributes of the Berry Springs Dolomite Aquifer, one could consider that limitations in the extent and characteristics of this aquifer could potentially expose the aquifer to vulnerable to changes in groundwater availability and quality, therefore impacting adversely on associated GDE's.

10.2 Flux, Flow and Level

Groundwater recharge is an important process for sustainable groundwater management, since the volume-rate extracted from an aquifer in the long term should be less than or equal to the volume-rate that is recharged. Land uses requiring the extraction of groundwater resources, can in large volumes, effect aquifer storage capacity, be depleting resources during the dry season. Over a long term this can have significant impacts on groundwater availability for environmental flows in GDE's.

Although quite a deep aquifer with potentially quick recharge residence time; over extraction of groundwater resources to accommodate surrounding land uses such as agriculture and aquaculture could see a reduction in groundwater availability and place undue stress on the equilibrium state of the aquifer. As a result of this reductions in spring head loss at topographic lows (i.e. Parsons Spring located in saltwater reaches) could see the back-siphoning of saltwater and/or contaminants into the freshwater aquifer rendering the source unsuitable for human consumption. Over extraction could also lead to cease of flow in GDE's through the reduction of head loss in springs.

Under the *Water Act (2008)*, Northern Territory Government licensing regulations stipulate that for developments other than stock and domestic purposes, a water extraction licence is required for the extraction of surface and ground waters. Licences are granted in one of two circumstances;

1) Outside a Water Panning Area, applicants must apply for an extraction licence and the 80/20 principle is applied (Lancaster, Unpublished). Outside planning areas environmental water requirements are not available to determine a sustainable extraction limit based on true environmental needs. Therefore the amount of 80% of all flows is reserved for the environment. This allows for the licensing of up to 20% of a groundwater or surface water resource dependent of total available flow/capacity at the required time of extraction. The 80/20 principle is also considered for water bodies where in which surface water and groundwater interact (such as GDE's) and therefore is extended across both resources whose capacity and flow are considered as one (Lancaster, Unpublished); or

2) Within a Water Planning Area, the aim is to determine the environmental needs. This in turn works out a sustainable consumptive pool. All licenses are within this consumptive amount allocated which is split between beneficial uses. Beneficial uses are established under the Water Act (2008) and assist in the fair division and planning of water resources within management areas. Applicants in Water Planning Areas must undertake different process to apply for surface and ground water resources.

Berry Springs is not currently within a Water Planning Area. Water Allocation Planning in anticipated to commence in this region in 2010.

Therefore if we were to apply the 80/20 principle in relation to flow data collected during this study from Berry Springs in 2008-2009, it is expected that figures presented in column 3, would have to be adopted as a minimum for surface water extraction to maintain flows of 80% to the environment. It should however be noted that flow figures presented below should only be used as a guidance in understanding possible flow regimes for future water allocation planning and that the re-establishment of Gauging station G8150027 at March Fly Creek Weir (downstream Berry Creek and at Monitoring Sites 3 & 4) would provide a true comprehensive picture of the spring discharge for Berry Creek.

Date	Site 2 Flow Results (M3/s) (Downstream Gauge Site)	20% Available Flow	80% of Available Flow
4/28/08	1.22	0.244	0.976
5/8/08	1.123	0.2246	0.8984
5/21/08	0.944	0.1888	0.7552
6/24/08	0.703	0.1406	0.5624
7/28/08	0.572	0.1144	0.4576
8/25/08	0.512	0.1024	0.4096
9/23/08	0.237	0.0474	0.1896
10/25/08	0.179	0.0358	0.1432
4/29/09	0.943	0.1886	0.7544
5/25/09	0.699	0.1398	0.5592
6/21/09	0.663	0.1326	0.5304
7/23/09	0.558	0.1116	0.4464
8/23/09	0.498	0.0996	0.3984
9/29/09	0.239	0.0478	0.1912
10/15/09	0.175	0.035	0.14

Table 10.1- Application of 80/20 Principle against 2008-2009 Flow Results

Based on 2008/2009 flow data analysis and relationship with rainfall, flow is significantly reduced during drier periods of the year from July through to October, somewhere in the order of 0.175 M3/s to 0.572 M3/s indicating that Berry Creek is reliant on discharge from the Berry Springs Dolomite Aquifer all year round. 2008/2009 Standing Water Level results in RN28964 when compared with rainfall and flow data support assumption of close connectivity between surface water and groundwater at Berry Springs. If connectivity between surface water flows and groundwater resources is more prevalent closer to the discharge point of the springs this area would then be most influenced by water extraction from the aquifer.

Assurance in the conservation of the springs discharge at Berry Springs it is suggested that a water protection zone be established, excluding the area within the zone from the drilling of new bores, development of high density living and intensive pressure from extraction from current ground water and surface water supplies (such as those utilised by the Northern Territory Wildlife Park). Increased awareness of changes to standing water level and flow at Berry Springs and within observation bores is needed through increased commitment by government in regularly monitoring flow at Berry Springs in conjunction with current observation bore monitoring. Education and awareness programs in relation to impacts of ground and surface water extraction by government should be mandatory with all licensee holders, regional schools and the general public.

10.3 Impacts on Water Quality

Karst areas play an important role in the recharge of aquifers, bicarbonate budget and subsurface runoff is the main mode of discharge in karst dolomite systems. Hydrochemistry is dominated by Ca^{2+} and HCO_3^- ions. Small scale variations in lithology (presence of dolomite) and in CO_2 pressure may therefore explain space variations in hydrochemistry and enable waters of the same origin to be identified.

Dolomite karst characteristics such as; deep weathering and fracturing; increased resistance time to weathering due to parent rock and acidity of water substrate; and porosity of the substrate; play an important role in the movement of minerals and contaminants through and aquifer. The impact of contamination of the aquifer (via well heads, groundwater windows, etc) and thus resulting in contaminated discharge from springs is a true threat to surface water ecosystems dependent on groundwater flows. When combined with contamination of runoff from surrounding land uses such as agriculture and direct point source pollution, surface water environments along Berry Creek could be subjected to nitrification of surface waters and possible algal blooms (via injection of increased phosphates and nitrates contained within fertilisers).

Total dissolved solids (TDS) in groundwater consist of minerals, organic matter and nutrients that have dissolved in water from rocks, bedrock and soils. Karst aquifer systems are susceptible to increased rates of dissolution of carbonate rocks and contain water high in TDS. Regions underlain by rocks not susceptible to weathering, such as quartz-rich granite, generally have waters with low TDS levels. Major components of TDS in natural waters include: bicarbonate (HCO3), calcium (Ca), sulphate (SO4), hydrogen (H), silica (SiO), chlorine (Cl), magnesium (Mg), sodium (Na) and other major minerals. Bicarbonate can make up 50% of TDS in some streams.

The hydrological setting also exerts a strong control on the amount of TDS detected in natural waters. Groundwater generally displays high TDS values because it moves slowly and is in contact with large amounts of rock and sediment. On the other hand storm water runoff has low TDS because it moves rapidly and has limited contact with rocks and sediments. Because of this relationship, TDS is typically highest in streams flowing during low flow conditions (dry season) when groundwater is the primary source of water. During high flow conditions (wet season) stream TDS is generally lower because storm runoff is the primary source of water. Current TDS levels at Berry Springs are typical of that of a natural stream system, displaying level of 150-200 mg/L. Increases in TDS of 100-250 mg/L would see adverse effects on aquatic life and compromise water quality.

Secondly increase in the acidity of the water from pollution could assist in increasing fracture sizes in via dissolution of rocks and increase the movement of contaminants through a system before time has allowed the dilution or breakdown of contaminants as it travels through the system to surface at springs. This process could also affect groundwater biota inevitably altering aquifer attributes indefinitely. Increases in pH to ranges below 6.5 could have adverse impact on current stream biota and increases in mineral content due to mass loading would affect other parameters such as TDS and EC, and in turn have implications on organisms tolerant to changes in salt content in water.

Assurance in the conservation of the springs discharge at Berry Springs it is suggested that a water protection zone be established, excluding the area within the zone from the drilling of new bores, development of high density living and use of pesticides, fertilisers and other contaminants restricted. Direct discharge of pint sources should not be permitted within this zone. Increased awareness of changes to water quality at Berry Springs and within observation bores is needed through increased commitment by government in regularly monitoring water chemistry at Berry Springs in conjunction with current observation bore monitoring. Education and awareness programs in relation to impacts of aquifer pollution should be mandatory undertaken by government with all licensee holders, regional schools and the general public.

10.4 Managing Groundwater Extraction and Land Use Impact

The ACREA (2002) claims that catchments across Australia classed as lower condition catchments the 2002 assessment one where located in areas of most intensive land use, therefore the by improving land use practices we can improve the condition of these catchments. In hindsight to this there is also a need for further research into environmental processes at a base level (i.e. river, estuary, and wetland) and their links between one another that contribute to whole of catchment function as well as the documentation of current and perceived impacts of surrounding land use.

The ACREA Report also found that at the other end of the scale, 30% of catchments classified in the highest condition classes provided for an indication of prioritise for protective management. Most of the Northern Territory's tropical rivers and their catchments fall into this category under the ACREA (2002). Systems which are also subjected to water intensive practices such as Agriculture and a number of smaller water dependent uses such as domestic and cultural water requirements could be most at risk from over extraction and decrease in groundwater flows and direct degradation of GDE's.

There are three major land use impacts to Berry Springs which include water resource development, agriculture and urban developments. Although only a small proportion of the area surrounding Berry springs and its associated creek is officially recognized as a horticulture protection Zone under the NT Planning Scheme (2007), due to accessibility to sealed roads, proximity to port and rail facilities and associated town structures such as a local shop, fuel depot and a school, has attracted domestic and small-scaled commercial developments to the region. This is also intrinsically linked to availability of water and suitability of soils within the region for farming. Over extraction and the time residence increase in the drilling of bores are alarming. The map below of the properties utilizing the BSDA highlights the number of bores drilled in the region. The average pumping rate of each bore can vary from 2-20 L/s (NRETA, 2007).

Figure 10-2 Bores in the Berry Springs Dolomite Aquifer (NRETA Maps, 2007)

Under Northern Territory Government licensing guidelines, bores exceeding a 15L/s pumping capacity within the Darwin Water Control District must have a Ground Water Extraction Licence to operate. To date, there are only a small amount of commercially licensed properties in the region, mainly due to this exemption (DNRETA, 2007). Standard stock and domestic groundwater extraction levels are unknown in this Aquifer and NRETA Maps (2007) indicates that here may be well over 100 domestic bores in operation. Although domestic users are currently unregulated or licensed for extraction in this region, to assist in future water allocation planning and understanding the pressures placed on this resource and many alike across the Darwin rural area, the Department of Natural Resources, Environment and the Arts under the National Water Initiative are currently undertaking research through the Darwin Bore Metering project to better understand the water requirements of domestic users over a 3 year period (DNRETA, 2007).

Land use within the catchment include small scaled subsistence farming (mainly Asian vegetables and fruit trees), large commercial agriculture enterprises (mainly mangoes), A bottled water enterprise, caravan park and resort, Territory Wildlife Park, a school and Recreational Reserves, Berry Springs Nature Reserve, and the Northern Territory Wildlife Park.

Figure 10-3 Some Land Uses in the Bottom Half Catchment of the Berry Springs Dolomite Aquifer

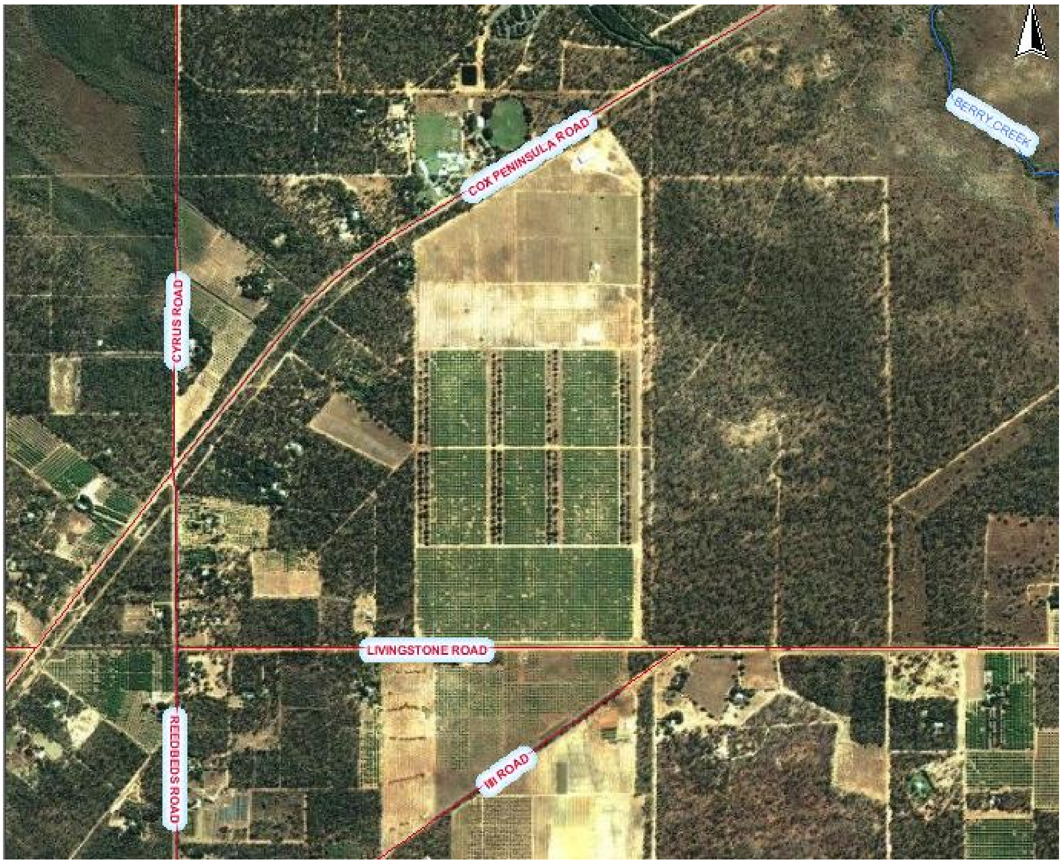


Figure 10-4 Some Land Uses in the Top Half of Catchment within the Berry Springs Dolomite Aquifer

To date there has been little research done on the impact of surrounding land uses on Berry Springs and/ or alterations in flow. It is estimated that in the Northern Territory there has been a relatively low level of groundwater development that has resulted on impacts to GDE's and there has been clear recognition within governments of the importance of GDE's, but the environmental water requirements for GDE's has yet to researched and developed (SKM, 2001). In GDE data deficient areas such as Berry Springs, it is important that governments and water management bodies gather sufficient information, scientific and cultural data (building on data collected in this study) to gain a greater understanding of the dynamics and significance of a resource before allocating it.

11. Recommendations

11.1 Recommendations Specific to Berry Springs

- Resurrection of Gauging Station G8150027 with the installation of a telemetered flow data logger and water quality lab.

- Establishment of regular water monitoring programs along Berry Creek and at Spring sites (including Parsons and Twin Farm Springs) to assess and document chemical and physical parameters including monitoring of phosphates, nitrates and other potential pollutants on a regular basis. A regular sampling program for phosphates, nitrates and other contaminates should also be undertaken in observation bores.

- Further research should be undertaken in understanding the dependency of specific flora and fauna within the Berry Creek system of groundwater flows, particularly during the dry season.

- Establishment of a water protection zone for Berry Springs, with boundaries based on groundwater movement rates, spring flow and water quality concerns.

- Implementation of a community and industry awareness program on water quality and physical attributes of Berry Springs and associated Dolomite Aquifer, either independently or in conjunction with community consultation programs associated with the 2010 Water Allocation Planning Process.

11.2 General Recommendations

It is recommended that the following groundwater protection measures be attempted for Berry Springs and other GDE's of significance in the North prior to or during the water allocation planning process in 2010.

a. The Northern Territory Government develop a comprehensive series of regional policies and procedures in accordance with policies and guideline documents developed by the Agricultural and Resource Management Council of Australia and New Zealand (ARMCANZ) under the National Water Quality Management Strategy.

b. Regional policy and long term management plan to be developed by the Northern Territory Government in relation the management of aquifers associated with sustaining Groundwater Dependent Ecosystems (GDE's) or resources reliant upon groundwater flows.

c. Greater planning provisions addressed in regional water allocation plans to GDE's; including but not limited to protection zones and provision for the exclusions of large scale land uses perceived to have adverse consequences on water quality and availability for GDE's.

d. Development of an advisory body with subscription of members from government, industry, community, planners and researchers to provide advice to government and industry bodies on groundwater protection.

e. An education and awareness program implemented in all facets of the public on groundwater protection and management with focus on the monitoring of groundwater extraction and GDE's.

f. Revision of the Northern Territory Mining Act (2001) to include licensing requirements, reporting and public transparency in relation to individual mine water management for all mines in the NT.

g. A revision of Beneficial Uses under the *Northern Territory Water Act (2008)* with greater emphasis placed on clear definitions of the Beneficial Uses with the addition of limitations and reporting requirements placed on mining developments.

h. A commitment by governments, research bodies and the private sector in undertaking and consolidating research programs, with the provision of sharing project specific information and results in better managing GDE's and planning for water allocations.

i. Restrictions placed on bore capacity, metering of high end uses and enforcement of metering reporting and requirements under law in aquifers susceptible to impact from pollution and water extraction.

j. Prohibition of a monopoly of an aquifer by any one licensee or beneficial use (aside that for environmental or water supply).

k. Greater involvement by Water Managers and Researchers in regional land use planning, including the need for greater understanding of water resources and environmental and cultural water requirements prior to the granting of development applications.

l. Territory/Commonwealth Governments and Industry (major licensees and mines) implement and maintain gauging stations, boards and observation bores in working order prevalent to the reporting of major GDE's with the potential to be effected by development.

m. The implementation of well-head protection zones and monitoring requirements in medium to large scale industry and agricultural developments including mining. Well integrity assurance should be implemented for areas outside water control districts.

n. Large scaled licensees (including mines) should be required to undertake a Groundwater Contamination and Extraction Impact Assessment of the concerned aquifer prior to approval for development with the implementation of a management plan and regular monitoring program for the life of the development, with results reported to the Northern Territory Government every 3 years. A Contamination management plan should also be submitted with commitments of the licensee in managing contamination issues if to arise.

12 Conclusions

Impacts other than hydrological must have equal consideration when undertaking an assessment and assigning management provisions for GDE's as it is not only the water associated aspects of these uses impacting on GDE's but the use of the land itself. It is essential that during the process of water allocation and planning that the environmental integrity of these systems are well researched, documented, managed and that policy is implemented to ensure that the potential threats of land use are limited and understood to maintain ecosystem health. This should ring true for water allocation in the Berry Springs in 2010.

GDE monitoring programs should not only be designed in catchments under threat or already impacted by humans to ensure adverse impacts upon them are not accelerated. They should also look at GDE's not yet subject to human impacts, and monitor them prior to potential impacts, in order to assist in better planning and conservation of GDE's in the north in light of potential expansion for development and increases in population.

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Appendices

APPENDIX A- GROUNDWATER MAPS

Dry and Wet Season Groundwater Movement Paths (Verma, 2001)

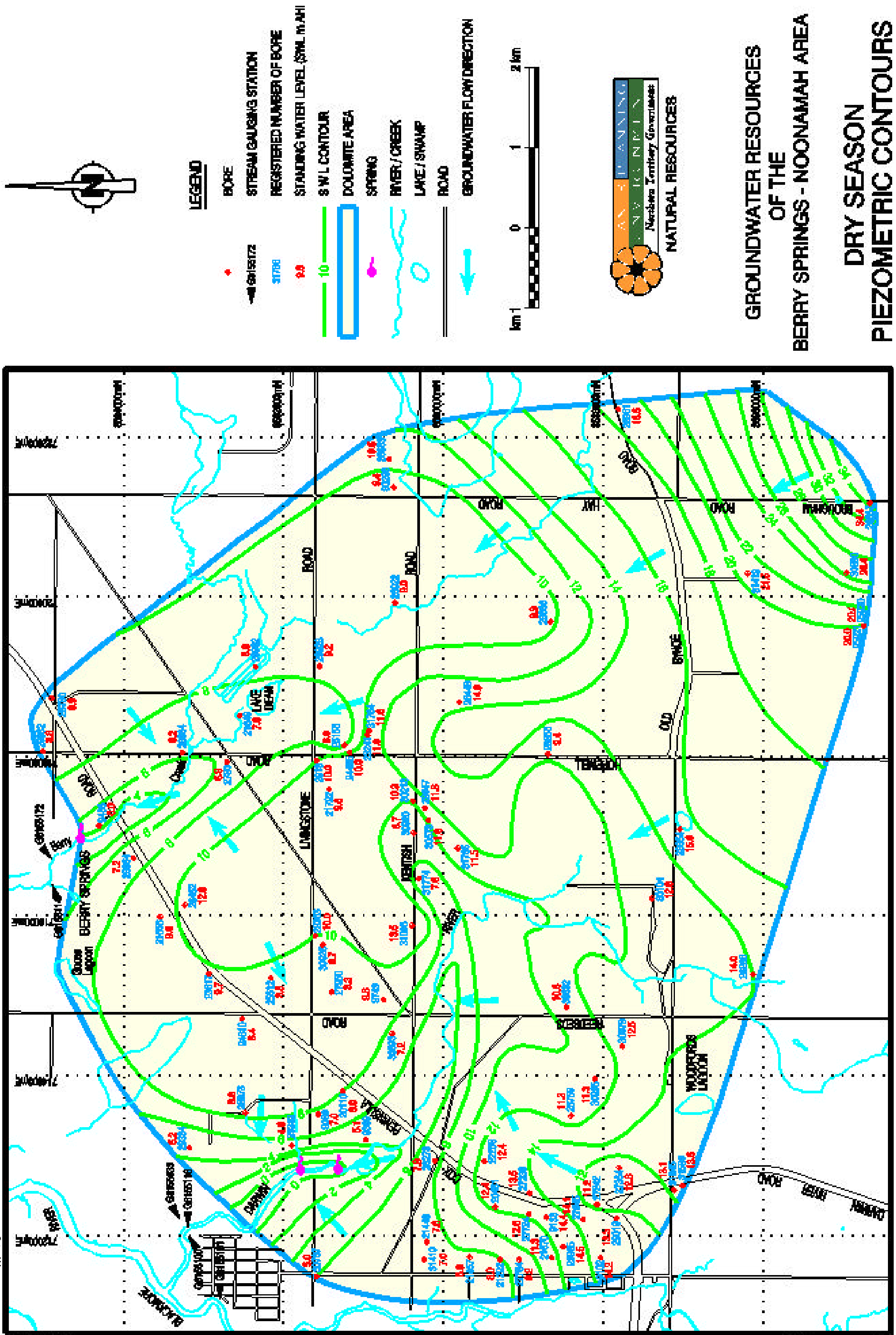

Figure 14

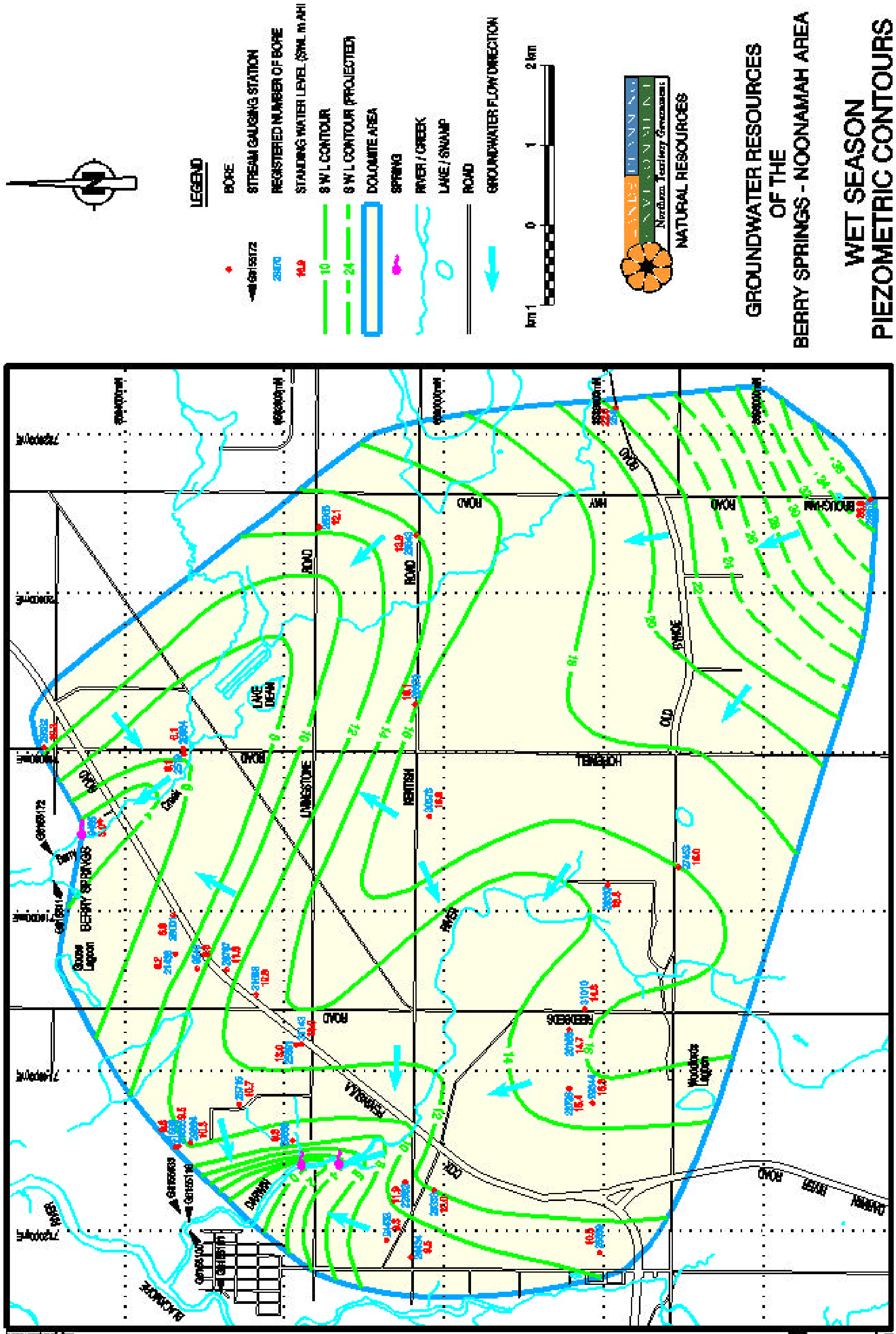
LEGEND
BORE
STREAM GAUGING STATION
REGISTERED NUMBER OF BORE
STANDING WATER LEVEL (SWL m AHD)
S W L CONTOUR
S W L CONTOUR (PROJECTED)
DOLOMITE AREA
SPRING
RIVER / CREEK
LAKE / SWAMP
ROAD
GROUNDWATER FLOW DIRECTION
NATURAL RESOURCES
GROUNDWATER RESOURCES OF THE BERRY SPRINGS - NOONAMAH AREA
WET SEASON PIEZOMETRIC CONTOURS

Figure 15

APPENDIX B- SITE PHOTOS

<u>Site 1</u>- Monitoring conducted upstream from V- Notch Weir and Berry Springs Recreational Reserve Fenced Boundary (Evident in Plate 1)

Plate 1- V-Notch Weir 8 m Downstream of Site 1. Climbing Over the Fence Was a Regular Occurrence During Data Collection.

Plate 2- Discharge of Water from Fracturing in Creek Base at Monitoring Site 1. This is Seen in Places Upstream and Downstream of Site 1.

Plate 3- Looking Downstream From V-Notch Weir and Boundary Fence (Upstream of Site 2 but Downstream of Site 1).

Plate 4- Small Waterfall and Cave, Downstream from Monitoring Site 1 (a Popular Swimming Site Upstream from Main Pool)

Monitoring Site 2-Downstream of Main Pool. Has been modified with the implementation of a swimming platform. Flow is channelled through this narrow section during the dry season.

Plate 5- Monitoring Site 2

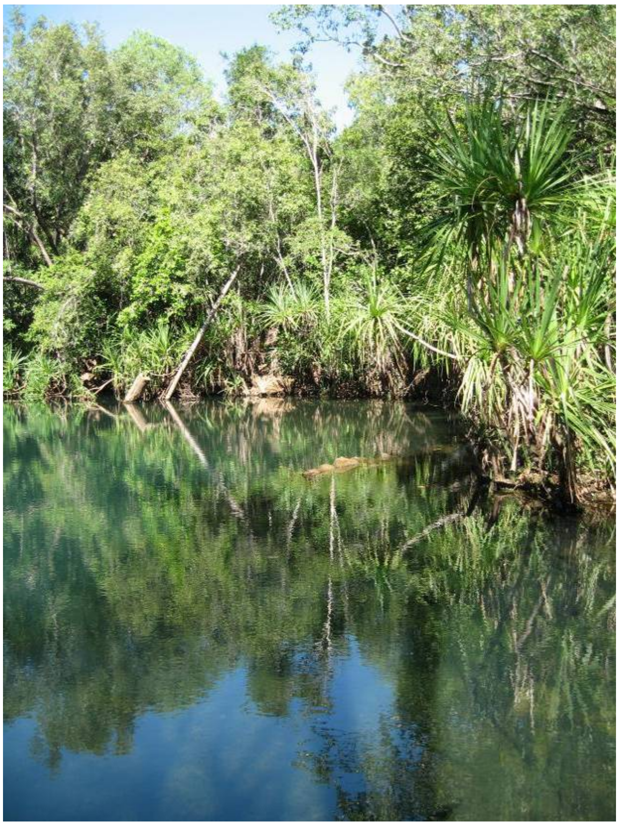

Plate 6- Main Pool (Upstream of Monitoring Site 2)

Plate 7- Main Pool (Upstream Monitoring Site 2)

Plate 8- Monitoring Site 2 flooded During February 2009

Site 3- Freshwater side of March Fly Creek Weir (downstream of Berry Springs Swimming Area and Site 2).

Plate 9- Site 3 Monitoring Point Above March Fly Creek Weir (Freshwater)

Plate 10- Shale Outcropping


Plate 11- March Fly Creek Weir

Site 4-Downstream of March Fly Creek Weir (Downstream of Site 3) and subject o influence of mixing of freshwater and saltwater at high tide (brackish).

Plate 12- Facing Downstream of March Fly Creek Weir (North).

Plate 13- Monitoring Site 3 at Base of Weir (Away From Turbulent Waters)

Additional Photos- Photo's of Berry Springs

Plate 14- Seepage Aided by Wet Season Runoff (1 March 2009)

Plate 15- Berry Creek (From Cox Peninsula Road) April 2009

Plate 16- Mertyns Water Monitor, Swimming Platform of Main Pool, July 2008

Plate 17- Springs at Site 5, Territory Wildlife Park.

Plate 18- Swimming Pool 3 (Upstream Sites 3 & 4 and Downstream 20m of Site 2)