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Hydrological Capture Zones Of Wetlands

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1. INTRODUCTION

Wetlands are shallow surface water bodies which are either permanently or seasonally wet. A geometric classification of wetlands comprises basin wetlands (lakes etc.), linear wetlands (rivers, drains etc.) and flat wetlands (palusplains and floodplains). An alternative classification distinguishes between groundwater recharge, discharge and flow-through wetlands. A wetland may receive inflow from two distinct sources – surface water and groundwater. A surface water, topographic catchment comprises the surface water capture zone, and is readily defined by reference to contour maps. The geographical extent of land from which recharge eventually discharges to a wetland is referred to as the groundwater capture zone. Whereas all wetlands have a surface water capture zone, only those in direct hydraulic connection with a shallow, unconfined groundwater system have a groundwater capture zone as well. In recent years there has been increasing emphasis on water quality management in wetlands, as distinct from flood mitigation. Wetland water quality issues therefore require management of both types of capture zones where they exist. It follows that management of one type of capture zone, without attention to the other, will not result in appropriate wetland management outcomes.

The proceedings of an International Conference on wetlands held in Perth in 1996 (McComb & Davis, 1998) contained a keynote address with the clear message that wetland water sources (surface and groundwater) need to be mapped and managed. The proceedings and subsequent Australian literature do not do justice to the conference – capture zone mapping is largely ignored in wetland management.

Mapping of the groundwater capture zones of rivers would greatly assist in developing an understanding of the source of pollutants. Groundwater discharge estimation for example to the Canning River, Perth would assist separation of surface water and groundwater nutrient inputs into the river system (Gerritse, 1999; EPA 2000). Similarly, groundwater inflow to a flowthrough artificial wetland (JDA, 1997) is a component of a water and pollutant mass balance, essential for predicting long term water quality. However, there are currently no accepted protocols for mapping groundwater captures zones of wetlands. This paper examines the relative importance of surface water and groundwater capture zones, particularly in urban areas of Australia, and refers to the issues of definition and management of groundwater capture zones for wetlands, while allowing appropriate land uses to occur within them.

2. WETLAND MANAGEMENT ISSUES

Wetland water quality management issues can be summarised as:

- Management of water levels
- Buffer zones for wetland protection
- Land management within capture zones

Wetland water quality depends on the quality of groundwater and surface water entering the wetland as well as on the chemical and biological processes taking place within the wetland. The concept of a “groundwater capture zone” for a wetland has implications for management, in that it defines the shape of a region of the land surface within which any recharge will ultimately pass through the wetland. In this way the capture zone defines perhaps the largest “buffer zone” that could be required to be protected, in order to protect the quality of a surface water body in perpetuity (Townley *et al.*, 1993, p.32)

3. SURFACE WATER AND GROUNDWATER CAPTURE ZONES

Figure 1 indicates schematically the relative sizes of a local surface water capture zone (or catchment) compared with the regional groundwater capture zone. In areas like Perth, which is underlain by an extensive unconfined aquifer, the groundwater capture zone of a wetland will often be many times greater than that of the local surface water catchment. Much of the surface water in the groundwater capture zone will be infiltrated in infiltration basins (sumps). Figure 2 shows an alternative situation where the water table is either deep (always below the bed of the wetland) or there is no groundwater system at all. In this instance, there is only a surface water capture zone.

There are a great many lakes in different hydrologic settings in Australia, the management of which could benefit from systematic interpretation on the basis of surface and groundwater capture zones.

Townley *et al*. (1993) reviewed the literature on lake groundwater capture zones including 150 lakes in 12 states and provinces of North America. In Australia the study of groundwater flow systems near salt lakes is of interest because of the large number of such lakes in Australia. In addition, groundwater capture zones of Lake Charm in Victoria and Lake Vermingon on Fraser Island off the coast of Queensland have also been studied.

Within the context of Australian urban groundwater and wetland management, groundwater capture zones for wetlands have only been documented for Perth (Townley *et al.,* 1993). The literature on other capital cities (Allison *et al* 1998; NSW EPA, 1997; Wong *et al.* 1999) does not refer to groundwater capture zones – either due to deep water table cases or lack of recognition of the phenomenon. Wetland management policy in urban regions without groundwater capture zones, needs to consider surface water management only.

Lawrence & Breen (1998), in a design guideline for Australian stormwater control ponds and wetlands, refer to the minor role of surface water in situations where groundwater inflows to wetlands. However the guidelines and examples cited are for surface water inflow management, rather than for groundwater management and hence are directed at deep water table cases.

It follows that Best Management Practices which address stormwater runoff quality (such as street sweeping, gross pollutant traps, detention basins, etc.) are appropriate for wetlands with surface water area capture zones only, but that a greater range of BMPs is required to protect wetlands that have a groundwater capture zone. These may include landuse controls and policies or regulations regarding pollutant inputs such as fertiliser application rates within the groundwater capture zone.

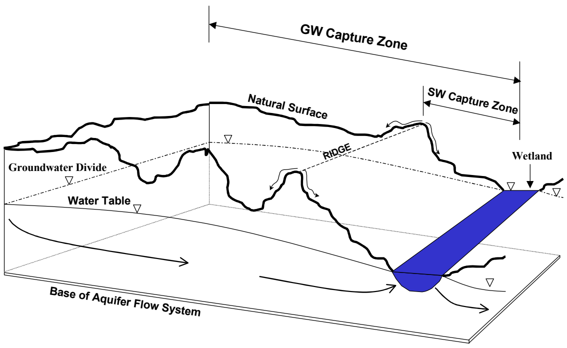


Figure 1: Surface water and groundwater capture zones of a wetland (shallow water table case)

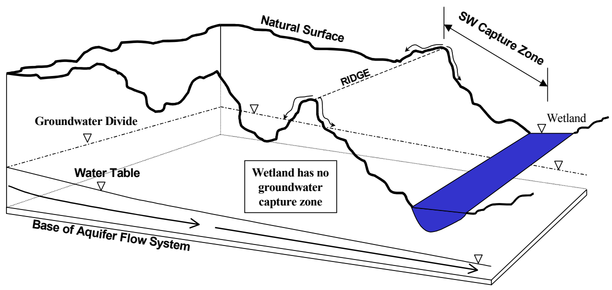


Figure 2. Surface Water capture zone of wetland (deep water table)

4. MAPPING OF GROUNDWATER CAPTURE ZONES AND LAND USE

Townley *et al.* (1993) describes modelling approaches to groundwater capture zone mapping. The hierarchy of models developed allowed quantitative predictions of geometries of capture and release zones of shallow flow through lakes:

- The depth of a capture zone depends largely on the ratio of lake length (in the groundwater flow direction) to thickness of the aquifer.
- A lake in an isotropic aquifer with length equal to the aquifer thickness draws water from roughly the top half of the aquifer.

- A lake 5 or 10 times longer than the aquifer thickness in an isotropic aquifer draws water from virtually the whole thickness of the aquifer and discharges water to the same depth.
- The width (transverse to the direction of groundwater flow) of capture zone is predicted to be twice the width of the open water surface in the wetland.
- The apparent groundwater capture zone shrinks during a dry season when wetland surface area is least, and expands during a wet season when wetland surface water area is greatest.

A simple way to visualise these concepts is to consider that each water droplet will follow the path of least resistance from its source in a recharge area towards its discharge point, a river, wetland or the ocean. It requires less energy for water at the base of an aquifer to rise 50 m into a wetland and then travel hundreds of metres horizontally in the water body itself and then to flow 50 m downwards again, as opposed to flowing hundreds of metres along the bottom of the aquifer where there is negligible driving force because the water table above is perfectly flat (Townley *et al.* 1993, p.27).

The area between the wet season and dry season groundwater flow divide may or may not be part of the groundwater capture zone depending on the relative direction, duration and velocity of groundwater flow towards or away from the wetland. If groundwater at some point in the flow domain flows towards a wetland for part of the year, and away from the wetland for the remainder of the year, the ultimate destination depends on the groundwater flow vector addition.

In reality the wet season groundwater divide represents the maximum land area from which pollutants could potentially discharge into a wetland. Given that all landuse activities have some potential for pollution of a shallow aquifer there needs to be a trade off between wetland protection and economic landuse.

In Western Australia, the State Government has issued a draft guidance for land management within the groundwater capture zone (Environmental Management Areas) of wetlands (EPA, 1998). Within the EMA of nationally or internationally significant wetlands the policy approach taken in the assessment of new proposals is to recommend as follows:

- Rural land uses which use large quantities of chemical (in particular fertilisers, pesticides and herbicides) or groundwater are not permitted.
- Minimum acceptable lot size of 2 ha.
- Presumption against further urbanisation and industrial landuse.

There is clearly a need for reliable methods to be used to map groundwater capture zones of wetlands, both to adequately protect the wetland itself, but also to allow reasonable land uses both within and beyond the capture zone.

5. GROUNDWATER CAPTURE ZONE MODELLING

The concept of a groundwater capture zone has its origins in the study of borefields, or individual pumping bores. It is often desirable to be able to identify the area at the land surface where natural recharge is ultimately pumped from a bore. Some wetlands recharge an underlying aquifer throughout the year. Others act as permanent discharge zones, while others act as flow-through water bodies, receiving groundwater over part of their bottom surfaces and recharging surface water to the aquifer over the remainder. A discharge lake acts to some extent like a large diameter well, except that the rate at which water is removed from the ground is not known *a priori*. Both discharge and flow-through water bodies have capture zones that can be predicted by systematic groundwater modelling.

One way to identify a groundwater capture zone, both within the ground and its projection to the land surface, is by using so-called particle tracking methods to trace the path followed by droplets of water or small massless particles carried by the water. Particles can be tracked forwards, to see if they reach a wetland, or backwards from the whole of the bottom surface of a wetland. A prerequisite for successful particle tracking is a robust calibrated groundwater flow model that correctly represents the hydrogeological system in the region surrounding a wetland of interest. Groundwater flow is inherently a three-dimensional process. However under certain circumstances, flow is sufficiently close to two-dimensional that it can be well represented by a two-dimensional model. A very long wetland, like a drain, oriented perpendicular to the average direction of groundwater flow can be modelled well by a 2D model in vertical section. This technique has been systematically explored by Nield *et al.* (1996), but is rarely applied in practice.

A large shallow lake in a shallow aquifer (with saturated thickness much less than the width or diameter of the lake) tends to have an almost hydrostatic zone beneath the lake, as if the lake is fully penetrating. Such systems can in principle be simulated using 2D models in plan. However in reality, flows near the upgradient and downgradient shores of a large flow-through lake have significant vertical components (Townley and Trefry, 2000), thus 2D modelling is an approximation.

The best way to simulate a wetland is to prepare a full 3D model, with a good representation of hydrostratigraphy at both regional and local scales (in the near vicinity of the wetland). The model should extend to meaningful hydrological boundaries, and certainly beyond the extent of the capture zone of interest. Packages such MODFLOW (e.g. in the GMS graphical environment) and FEFLOW are capable of computing steady state flow in 3D and tracking particles to define capture zones with good precision.

Recent research has demonstrated the importance of simulating dynamic seasonal flow patterns in order to properly assess capture and release zones of wetlands (Smith, 1999). Dynamic fluctuations can cause water released by a wetland to be recaptured, and water nearly captured to avoid capture. Unfortunately the particle tracking routines available in many modelling packages do not robustly handle particle tracking in unsteady flows.

For practical reasons, it is not uncommon for 2D models to be used to assess the capture zones of multiple water bodies in a regional aquifer system. This approach is reasonable for regional assessments, but more detailed modelling may be required to refine predictions in critical or controversial situations. Common difficulties include lack of sufficient knowledge about hydrostratigraphy and hydrogeological properties, lack of sufficient knowledge about natural recharge and evapotranspiration processes that drive fluxes across the water table, and lack of resolution to define the shape of the boundary of a wetland. Furthermore, there are no modelling packages currently available that adequately accommodate transient boundary conditions, such as when wetlands grow and shrink in size seasonally. Such capabilities need to be developed to allow accurate prediction of capture zones for seasonally dynamic wetlands.

6. GROUNDWATER CAPTURE ZONE BASED ON WATER TABLE DATA

An example of the degree of uncertainty in mapping the extent of a groundwater capture zone is illustrated by unconfined groundwater level data collected on the northern side of Forrestdale Lake, an internationally significant wetland with RAMSAR Convention listing (UNESCO, 1971).

A network of approximately 50 water table monitoring bores was installed and water table elevations contoured to infer the location of the wetland groundwater capture zone on several occasions in 1999 and 2000.

Figure 3 shows a comparison between water table divides in January and September 2000, and the current EMA boundary (EPA, 1998) based on groundwater modelling (Dames & Moore, 1996).

The summer data (Figure 3a) indicates a groundwater divide closer to the Northern Lake edge than the EMA boundary. Rainfall in winter 2000 was close to the long term average and by September 2000 the water table had risen to the surface with some surface ponding and flow in agricultural drains towards the lake. Consequently, the groundwater divide moved north to include an area affected by the drain indicated on Figure 3b.

It is useful to consider a groundwater capture zone for Forrestdale Lake and also a groundwater capture zone for Southern River, effectively a linear wetland to the north east of the lake. The apparent boundary between the two capture zones moves during the year. Within the area over which this movement occurs it is less certain where the groundwater will eventually discharge, either to Forrestdale Lake or to Southern River. For most of the year (perhaps November to August) while the water table is below the natural surface, the water table divide is closer to the lake and groundwater flow is probably towards Southern River as indicated by the January 2000 data. Only during months when the water table reaches the land surface (perhaps September and October) will the water table divide be further from the lake and the groundwater flow be towards the lake. Vector addition will determine net flow direction.

There is a tendency therefore to believe that the net movement within this boundary zone will be towards Southern River. The final destination, however, cannot be determined without detailed tracer experiments or detailed dynamic modelling, or both.

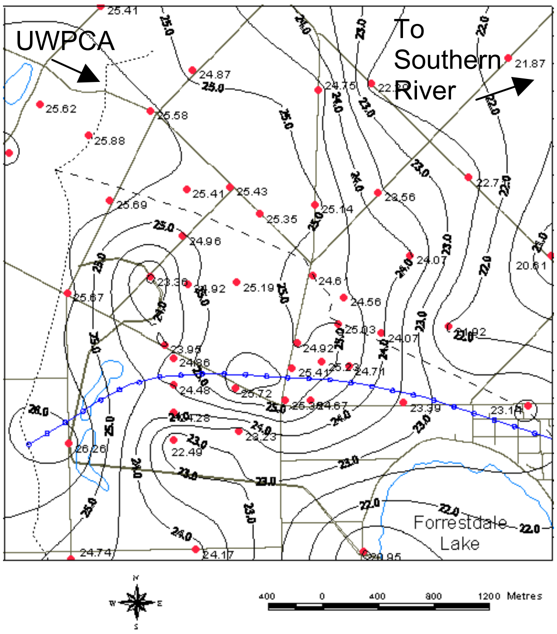
The apparent capture zone of a wetland in Perth is expected to be greatest at the end of winter (maximum water table) and smallest at the end of summer (minimum water table). To some extent the data confirm this pattern, although the effect of agricultural drains appears to have increased the winter capture zone above what may have occurred naturally. The drain shown on Figure 3b may have modified the natural groundwater flow pattern and increased the capture in September 2000.

The extent to which restoration of the natural surface contours of the land, such as by filling of the drains, would restore the water table divide to its more natural position has not yet been assessed.

The time lag between transmission of water table changes to depths typical of the saturated thickness of the unconfined aquifer (typically 30 m) is not known – it may be of the order of days or weeks. Also the direction of groundwater flow in the deeper part of the unconfined aquifer may not be as affected, or to a less extent, than the groundwater immediately below the water table.

From the point of view of lake management and prevention of pollution entering the wetland it may be necessary to develop this concept of there being three "groundwater capture zones" worthy of consideration, namely:

- Surface water (including current and planned drains)
- Local shallow groundwater systems exhibiting seasonal and possibly annual differences
- Regional groundwater systems perhaps best estimated using deeper slotted bores.



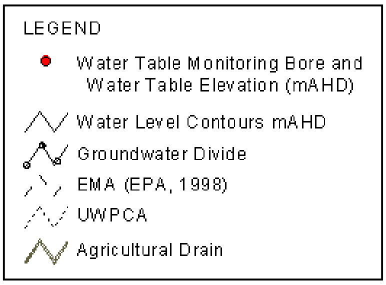
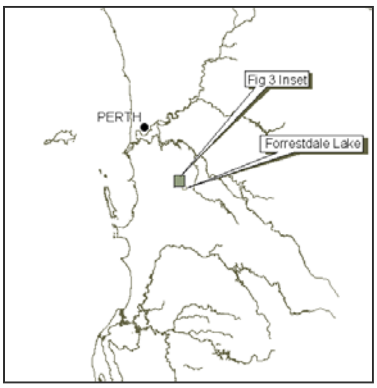


Figure 3a) January 2000 groundwater contours and estimated groundwater capture zone.



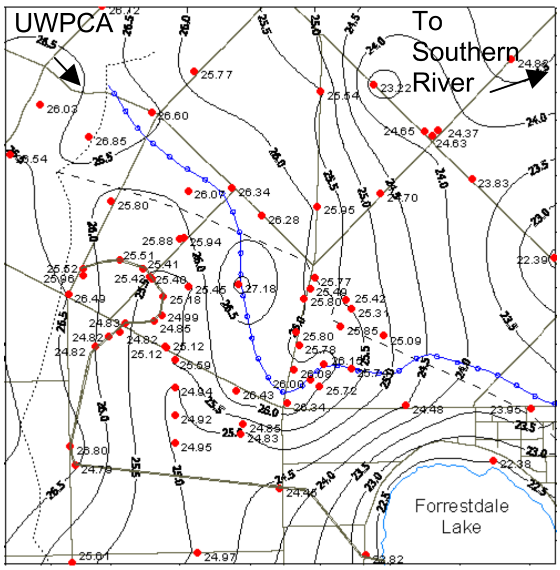


Figure 3b) September 2000 groundwater contours and estimated groundwater capture zone

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CONCLUSIONS

Protection of the water quality of wetlands requires consideration of both surface and groundwater captures zones. Whereas surface water capture zones are readily delineated by topographic maps, groundwater capture zones require more sophisticated methods including modelling and appropriate hydrogeological data (stratigraphy, conductivity etc.) Steady state particle tracking software is unable to account for seasonal movements in groundwater divides and hence seasonal variations in groundwater flow directions. The extent to which seasonal water table fluctuations can be interpreted as representing conditions throughout an unconfined aquifer requires further investigation.

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