4 Method

The assessment of GDE sensitivity is based on a combination of species tolerance modelling, remote sensing data, and hydrogeologic evaluation. The sensitivity analysis was performed on two trial areas – the Portland Groundwater Management Area (GMA) in southwest Victoria and the Upper Loddon Water Supply Protection Area (WSPA) in central Victoria. The analysis relies on pre-existing data. No data collection or calibration was performed for this project. Thus, the conclusions are necessarily qualitative and should be used only as illustrations of the utility of the methodology and for targeting priority areas of concern.

The species tolerance model has been developed at the state-wide scale. The remote sensing analysis relies on the change between Normalized Differential Vegetation Index (NDVI) images for the mid 1990s and early 2000s. These images cover the whole state but the analysis was restricted to the Glenelg Hopkins Catchment Management Authority (CMA) region and the North Central CMA region. The hydrogeologic evaluation, based on groundwater level and usage data, was labour-intensive and only performed within the two trial areas.

4.1 Species Tolerance Modelling

Species Tolerance Modelling was performed by the Arthur Rylah Institute and the results supplied to DPI for this project. The model represents the initial development of the process, producing interim results that are not a fully realized data product. A journal article on the modelling is being prepared and the method will only be described briefly here.

The species tolerance model is based on field surveys of over 42,000 quadrat locations. A quadrat is a 'uniform' sample of the plant community. Approximately 36,000 of the quadrats were determined to be sufficiently reliable for the modelling. The vegetation species within the quadrats are related to a database of plant traits and attributes, such as life form and environmental tolerances. The environmental tolerances included in the model are:

Inundation: Records the maximum length of time a typical plant naturally endures inundation by water (any depth of water above the substrate surface – fresh or saline); and/or waterlogging near the soil surface (<30 cm); and/or encompassing most of the plant's root zone:

1) Taxon is not confronted with inundation or waterlogging in nature (response unknown)
2) Waterlogging or inundation <1 month
3) Waterlogging 1-6 months, inundation <1 month
4) Waterlogging 1-6 months, inundation 1-6 months
5) Waterlogging >6 months, inundation <1 month
6) Waterlogging >6 months, inundation 1-6 months
7) Permanent inundation (i.e. true aquatic)

Salinity: Records estimates of the relative tolerance of a species to saline environments. Includes saline soils, saline groundwater, or saline surface waters. It does not specifically address waterlogging.

1) Response unknown
2) Unknown but suspicion of salt tolerance (given taxonomic affinities)
3) Tolerant of salt spray (i.e. coastal)
4) Moderately tolerant of soil salinity/sodicity
5) Halophyte
6) Glycophyte

The species attributes were aggregated to include new target attributes or combinations of attributes. A subset of relevant site attributes were chosen to submit to clustering procedures and used as training data sets for modelling, using mapped environmental data as the independent variables. Ten radial basis function neural-network models were built using the training data sets with a subset of the quadrats reserved for evaluating the goodness of fit. A composite State-wide map of the model output was prepared from the maximum value from four models applied to each 25 X 25 m pixel:

1) The % of the total overlapping projected foliage cover that is tolerant of greater than 6 months waterlogging but less than 1 month inundation
2) The % of the total overlapping projected foliage cover that is tolerant of greater than 6 months waterlogging and greater than 1 month inundation but less than 6 months inundation
3) The % of the total overlapping projected foliage cover that comprises true halophytes
4) The % of the total overlapping projected foliage cover that comprises true aquatics

The species tolerance model result for Victoria is shown in Figure 7.

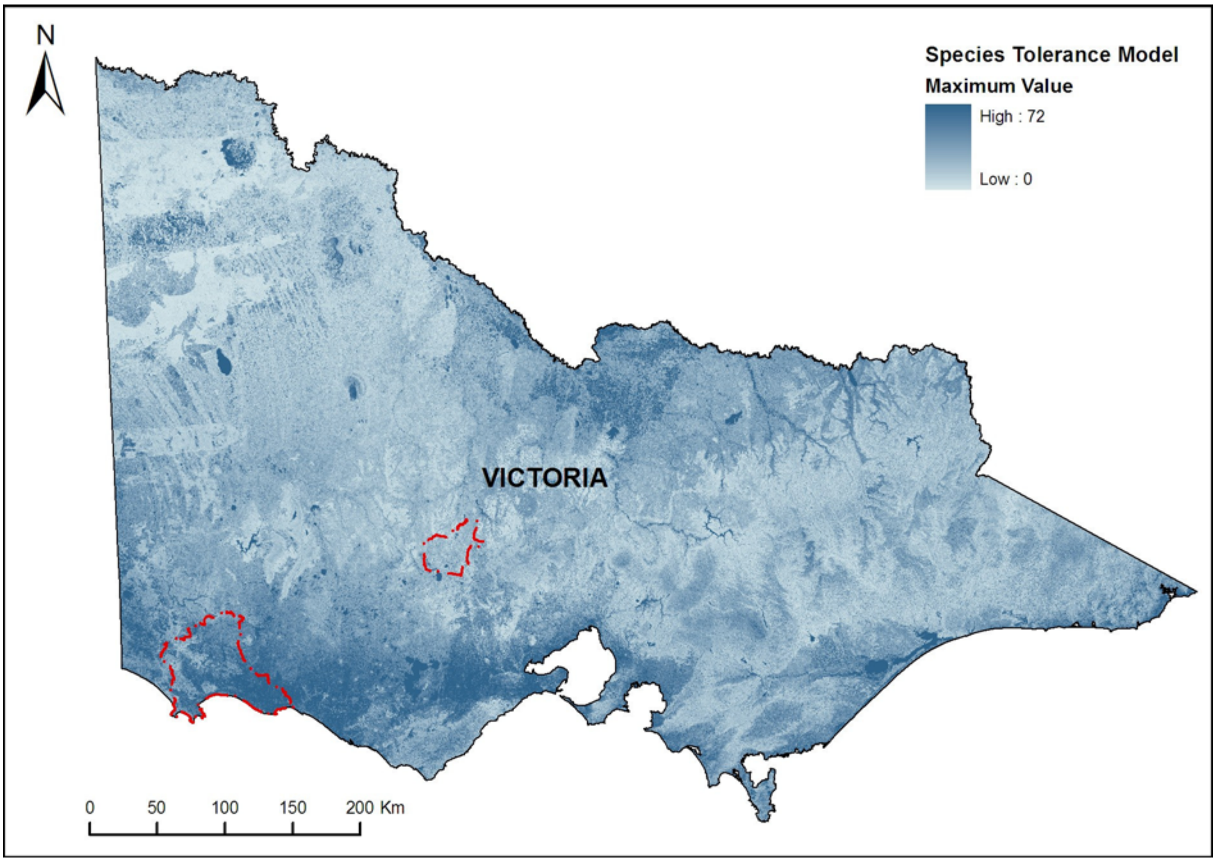

Figure 7 Species tolerance model for Victoria showing locations of the Portland GMA and the Upper Loddon WSPA

The species tolerance model does not directly consider deep-rooted trees that may access groundwater directly, with the exception of certain species such as *Eucalyptus camaldulensis* (river red gums) that are tolerant of inundation or waterlogging. Little is known about groundwater dependency by other native tree species, so much of the forest and woodland area is excluded from this sensitivity evaluation. The GDE mapping methodology (Dresel, et al., 2010) is believed to include large areas of upland forest that may not be groundwater dependent. Application of the species tolerance model allows the evaluation to focus on areas with the presence of vegetation that has known potential to use groundwater.

Species tolerance model results for potential GDE areas were extracted from the tolerance result raster data sets. Zonal statistics were then calculated for the species tolerance layer values within each GDE polygon. Caution is needed in interpreting the zonal statistical results because the polygons vary greatly in size and thus in the number of tolerance values included. Some small polygons of marginal interest did not overlap the centroid of a tolerance model pixel and thus had no statistical result. Very large GDE polygons included a large number of values and thus were more affected by skewed distribution, leading to larger means and standard deviations. For this reason, the median of the species tolerance statistic was chosen to represent the central value for each potential GDE area, and statistical hypothesis testing methods were not used in the overall interpretation. The median values are displayed on the figures, using an equal interval colour ramp.

4.2 NDVI Change Analysis

NDVI is a measure of photosynthetic activity across the landscape. The magnitude of the NDVI obtained from the Landsat satellite imagery is a function of the level of photosynthesis in the green vegetation and the percent of the land surface covered by the leaves.

Composite NDVI images for Victoria were obtained from the Australian Greenhouse Office (AGO). The data were provided by AGO at a 30 m resolution.

The data used were midsummer (generally February) images for a mid 1990s period of average precipitation and for post-2002 drought period. The difference in NDVI between the two images will reflect the effect of the drought on the vegetation.

The NDVI change was calculated by performing a pixel by pixel subtraction of the 2002 NDVI from the 1995 NDVI. Thus a positive value indicates that the NDVI was higher in the 1995 data set while a negative value indicates a higher NDVI in 2002. There are a number of important factors that can affect the NDVI difference values in addition to the drought effects. These include:

- Calibration differences. Atmospheric effects can impact the NDVI calculation. The radiance is preferably calibrated to top of atmosphere values to remove the majority of the atmospheric effects.
- Image dates. The Landsat images used in calculating NDVI are composites from different overpasses. Composite images were needed to provide complete coverage and to avoid cloud effects. Thus, there are edge effects with different values of NDVI seen for similar terrain and land use due to the difference in overpass used. The relative differences seen within a particular image remain relevant, but the absolute magnitude of NDVI is subject to systematic error. The desire was to use midsummer images but where the image date is sufficiently different between the two years, this will impact the NDVI. Table 3 shows the image dates used in the Glenelg Hopkins and North Central CMA regions. The zones produced by overlapping combinations of image dates for the Glenelg Hopkins CMA region are shown in Figure 8 and the zones for North Central CMA region in Figure 9. The zones show areas where discrepancies in the NDVI difference maps may occur due to the different date combinations, so relative differences should be assessed only within each zone. The Upper Loddon WSPA is located partially in the North Central CMA region and partially in the Glenelg Hopkins CMA region and was analysed within the North Central region.
- Local temperature and precipitation effects. Climate variability will affect the NDVI difference between years. For example, higher temperatures during a summer overpass can reduce photosynthetic activity while recent rainfall would be expected to increase photosynthesis. This will lead to the change calculated between two image dates not being representative of overall trends. To offset this influence, the focus will be on relative changes.

- Land use changes. Changes in land use can affect NDVI trends at particular locations. Change to irrigated pasture from non-irrigated or vice versa will typically have a large impact on NDVI, as will change from active cropping to fallow. Change from cropping or pasture to tree plantation will increase midsummer NDVI. Within forests, woodlands, or tree plantations, the NDVI can be affected by planting, harvesting, fire, or simply as the vegetation grows and canopy increases. These changes can often be identified through air photo or satellite image interpretation but that is not easily automated, and detailed land use evaluation is beyond the project scope. However, the land use changes are not likely to completely obscure the evaluation of GDE sensitivity. The potential GDE mapping generally excludes most agricultural land although plantations are often not filtered out.

NDVI difference values for the potential terrestrial GDEs were extracted by using the GDE map as a mask over the NDVI difference raster datasets.

Table 3. Image Dates for CMA Region NDVI Zones

Glenelg Hopkins CMA		North Central CMA	
1995 NDVI Image Dates	**2002 NDVI Image Dates**	**1995 NDVI Image Dates**	**2002 NDVI Image Dates**
24/02/1995	10/01/2002	07/01/1995	18/01/2002
03/03/1995	18/01/2002	24/02/1995	12/02/2002
	12/02/2002	03/03/1995	07/03/2002

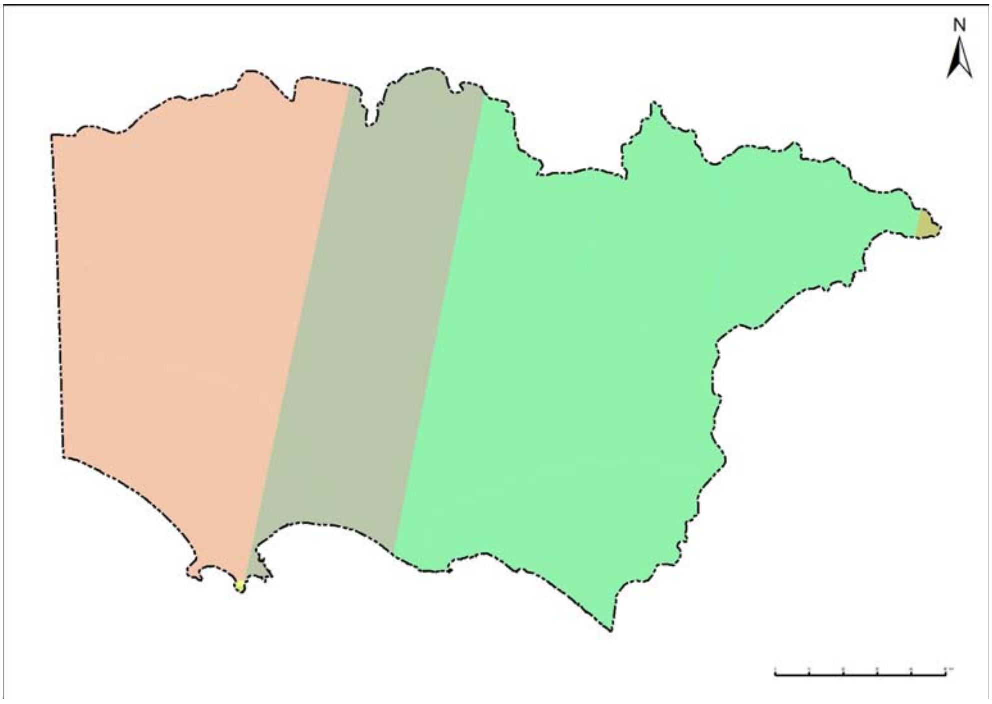

Figure 8 Image date zones for Glenelg Hopkins CMA region NDVI difference maps

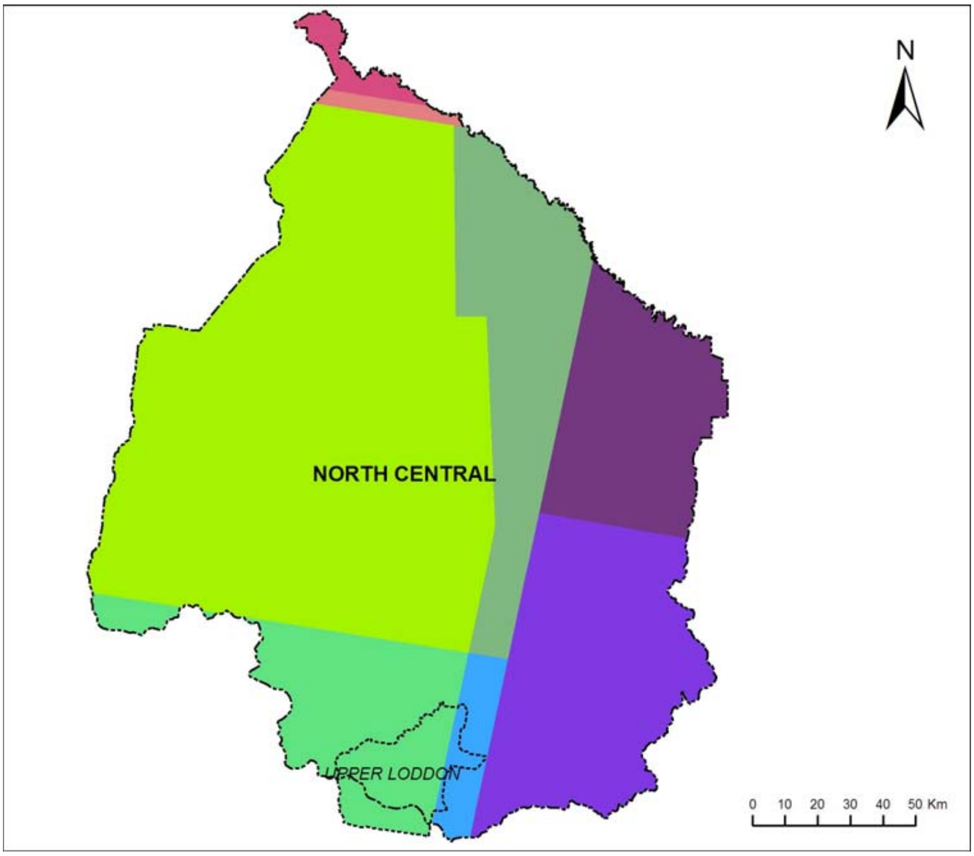

Figure 9 Image date zones for North Central CMA region NDVI difference maps

4.3 Hydrogeologic Interpretation

Groundwater monitoring bores with horizontal coordinates in the Portland GMA and the Upper Loddon WSPA were identified and their historical groundwater level data extracted from the Department of Sustainability and Environment (DSE) Groundwater Management System (GMS). Time-series groundwater levels were graphed with an automated procedure for each bore using the depth below natural surface (DBNS) where available and the depth below measuring point in other cases. Levels for nests of bores at different completion depths were plotted together to identify vertical hydraulic gradients.

Screen depths and total drilled depths were used together with geologic and driller's logs to interpret the aquifer monitored. Groundwater usage volume and location for the Portland GMA region was supplied by Southern Rural Water. Usage volume and location for the Upper Loddon WSPA was supplied by Goulburn Murray Water.

The Portland GMA region was subdivided by catchment for convenience of interpretation. Catchment boundaries were obtained from the Victoria Government Geospatial Data Library 'SDL_CATCH' GIS layer. An arbitrary 5 km buffer from the coast was applied and bores within that buffer were classified as 'coastal'. The monitoring bore locations and the subdivisions are shown on Figure 10.

The Upper Loddon WSPA region was divided by major catchment for interpretation. The CMA boundary essentially follows the Great Divide with Mount Emu Creek flowing to the south; Bet Bet Creek, Tullaroop Creek, and the Loddon River flow north. The monitoring bores and catchments are shown on Figure 11.

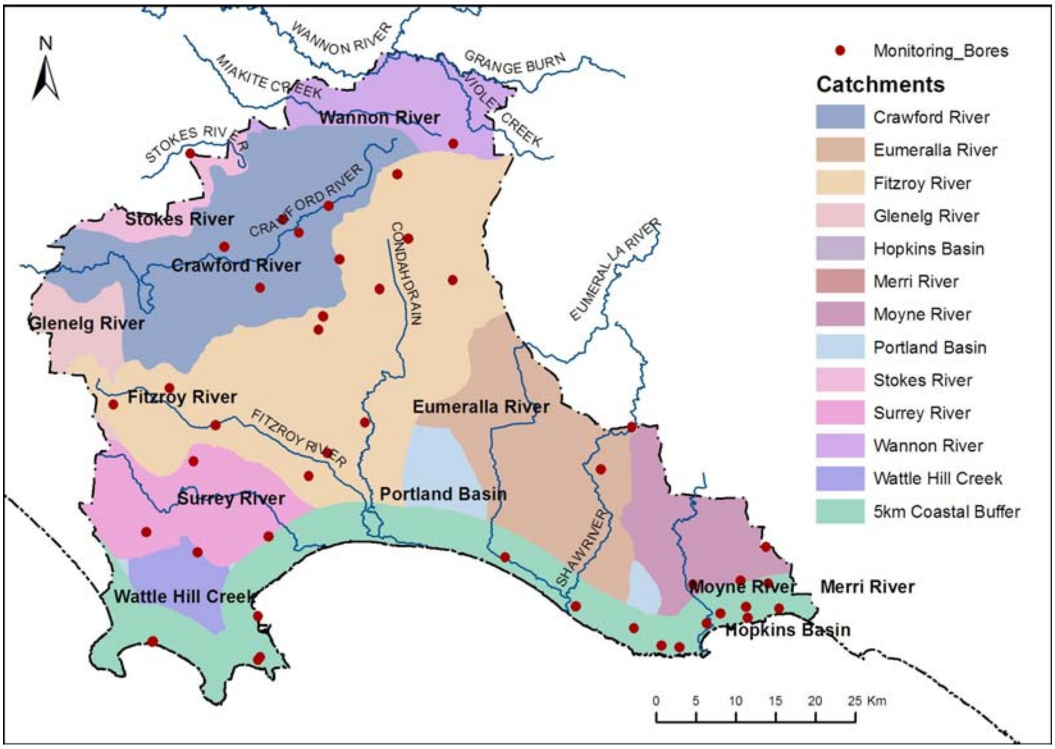

Figure 10 Catchment and monitoring bore locations in the Portland GMA region

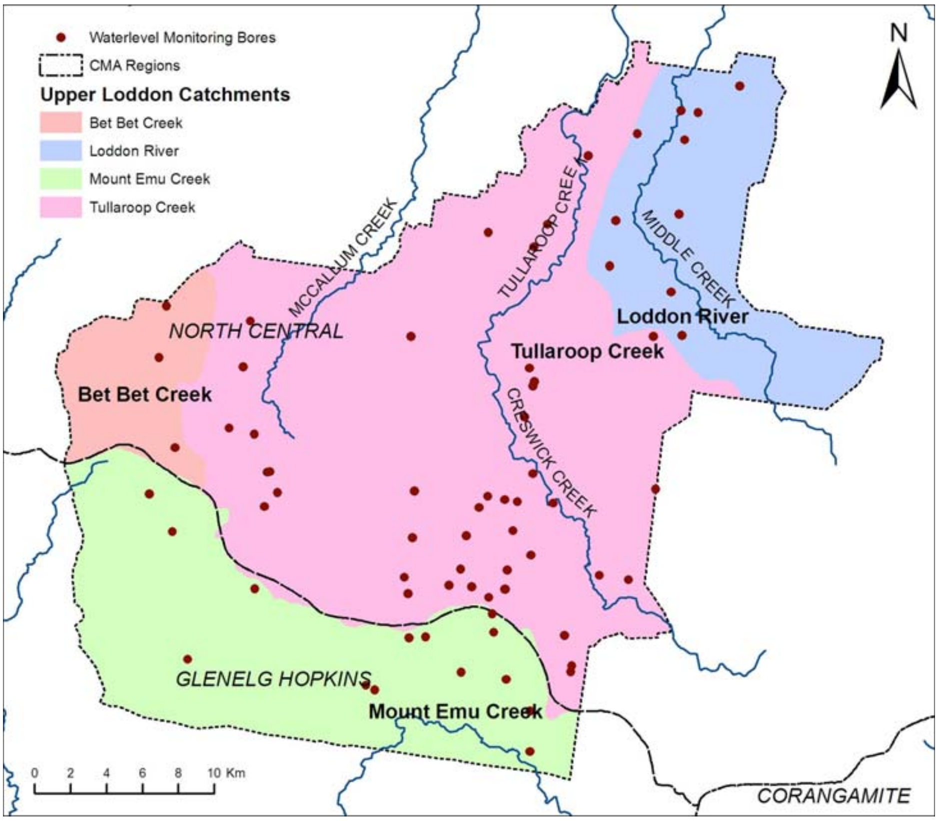

Figure 11 Catchment and monitoring bore locations in the Upper Loddon WSPA region

The water level data are not sufficient to create accurate piezometric surface maps for each aquifer. Thus there is considerable uncertainty of the depth to groundwater at potential GDE locations. Watertable depth for unconfined aquifers typically (but not universally) is greater along ridges and lower in valleys, forming a subdued reflection of the topography. In this case the watertable depth at a bore will be an upper bound of the depth towards the nearest stream. If the watertable at the bore is below stream level, groundwater discharge to the stream is precluded.

The piezometric surface for confined aquifers (static water level in bores) is above the top of the aquifer and will not be directly related to the topography. The water level depth indicates the *potential* of upward leakage towards the surface. However, the actual flow depends on the permeability of the intervening sediments. Where nested bores are completed in multiple aquifers at a location, the relative water levels indicate the potential for recharge to or discharge from the lower aquifer.

If a confined aquifer has a piezometric head near or above the ground surface, it may contribute to the maintenance of GDEs and wetlands. If the groundwater level trend falls below ground surface or the level where it can be reached by vegetation, then there is danger of degradation of the GDEs, even if the confined aquifer is still providing sufficient water to meet allocations.

Seasonal variation in groundwater level also provides an indication of possible aquifer connection to the surface. Strong seasonal groundwater level variability in a water table aquifer indicates active recharge in the flow system. Lack of variability could suggest one or more of the following: (a) the bore is not in good communication with the aquifer due to construction problems, (b) the bore is constructed in low permeability sediments, or (c) the amount of recharge is low. For confined aquifers, seasonal water level variability may result from changes in the upgradient recharge zone(s), but the variability will be damped further downgradient. The rapidity of damping is a function of the aquifer permeability. Seasonal variability in confined aquifers can also be the result of changes in the overlying aquifer where there are leaky confining layers, or through seasonal pumping.

The hydrogeologic interpretation is largely qualitative because the project scope does not include collection of site-specific data. For example, the potential for upward leakage from a confined aquifer can be assessed but the rate of discharge depends on the vertical permeability of the confining beds and is largely unknown. Little or no information is known about preferential pathways that may lead to groundwater seepage to wetlands or the surface. However, the trend in groundwater level data provides indications of changes that may threaten the ecological resources.