Developing ecological response models and determining water requirements for wetlands in the South-East of South Australia
Synthesis Report

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Key points

Groundwater dependent wetlands in the South-East of South Australia face multiple threats associated with declining groundwater level (Fig 1) and the interaction of this with climate change and increased risk of salinization. This project undertook a range of investigations involving satellite data analysis, field investigations and scenario modelling with a feature of the work being the different spatial scales of investigation undertaken. This provides insights into processes operating from wetland to regional scales. Much of the work is based on the development of a conceptual hydro-salinity classification for wetland habitat that is applicable to wetlands of the South-East. The classification can be used to quantify and compare habitat diversity within and between wetlands. Common wetland plants were assigned to hydrological (plant functional group) and salinity tolerance classes, allowing these to be positioned within the hydro-salinity classification. This provides a parsimonious but powerful framework for modelling probable changes in wetland plant communities that would result for reduced water availability. Complementary modelling work was undertaken demonstrating the use of such an approach.

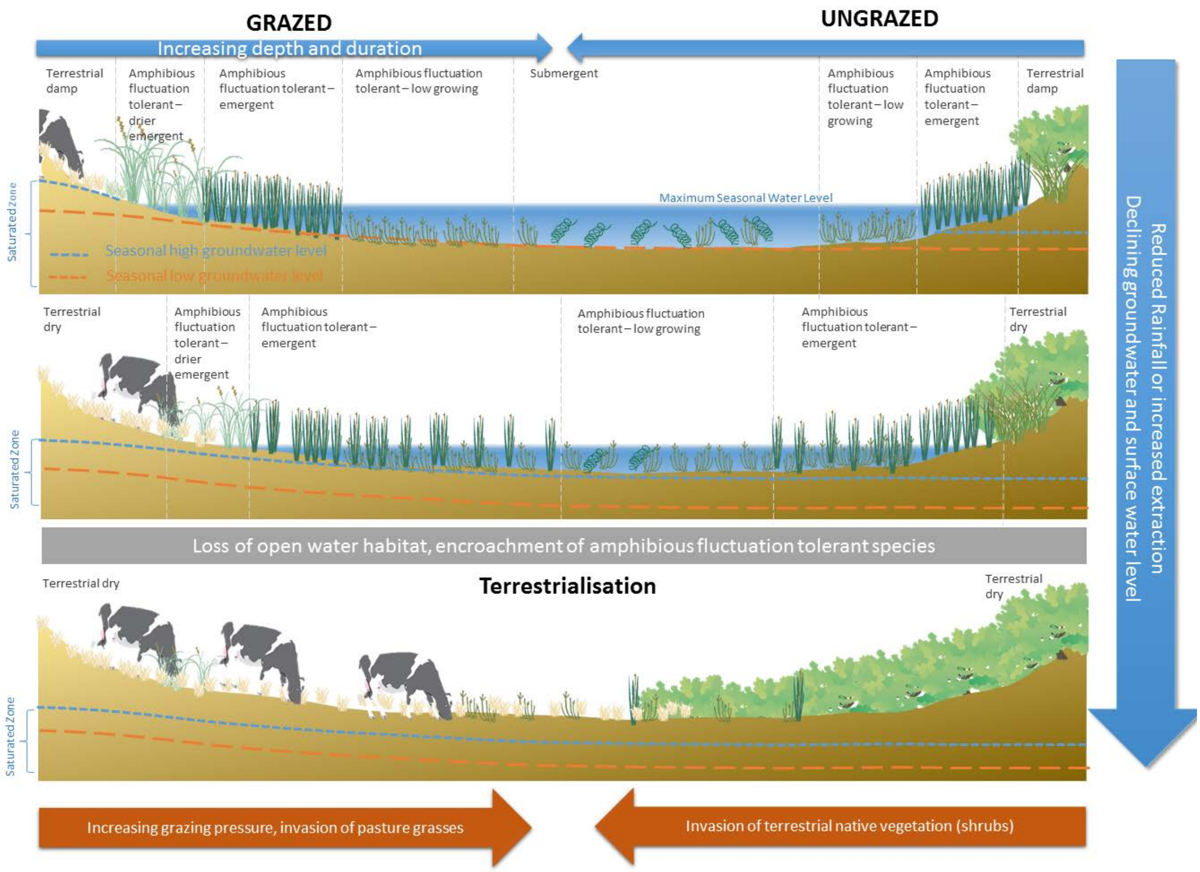

Figure 1 Conceptual model of changes in wetland plant functional group zonation as a result of declining water availability – figure adapted from Harding et al (2015)

Remote sensing time series analysis over the period 1990 – 2013 provided a region-wide picture of changes in wetland inundation and greenness – a measure of vegetation vigour. Most wetlands across the South-East experienced reductions in both greenness and inundation during the period 2003/04 to 2006/07, which then recovered over the period up until 2011. From 2011 to the end of 2013 both measures of wetland condition have again declined.

This project collected data from an extensive field sampling program across 12 wetlands and wetland complexes, allowing hydrological response models to be built and validated for the eight most common plant functional groups in the region. Plant functional groups are defined according to preferences for depth and duration of inundation and three different types of response to increasing water availability were observed. The probability of observing plant functional groups common in ecotone (fringing) zones of wetlands declines as water depth and duration increase. The submerged emergent (Se) functional group occupies the wettest part of this hydrological niche-space and the probability of occurrence increases monotonically above a minimum depth-duration threshold. Functional groups with intermediate needs for inundation (typically species classified as being amphibious) had unimodal (hump-shaped) responses, but exhibited different modes or tolerances, indicating slightly different preferences. This is consistent with ecological theory on niche differentiation supporting persistence of plants of different life histories or physiological tolerance to inundation and indicates the value of having a range of hydrological conditions within a wetland to support maximum habitat and plant diversity. The response curves can be used to assess hydrological data against the preferred range for each of the functional groups modelled either for prediction of change scenarios or for tailoring water regime to a preferred set of functional groups.

The plant functional group models were used in an ecological response modelling study for three scenarios of increasing levels of mean groundwater decline. Water allocation plans specify acceptable levels of decline in groundwater level below which any impact is considered to be acceptable and these thresholds were used in scenarios to quantify what changes may occur. The impacts of any decline in groundwater level will depend upon the wetland bathymetry. Shallow wetlands may be able to maintain functional group richness and zonation observed under current hydrology for drawdowns up to 0.25 m, but will begin to experience loss of functional groups and potentially multiple species, for groundwater level drawdown of 0.5 m or greater. A 1.0 m decline in groundwater level was predicted to create a risk of terrestrialisation across most of the wetland area. Deeper wetlands may be resilient to ecological changes for drawdowns up to 0.5 m but will be impacted by drawdowns of 1.0 m, including the loss of functional groups. Changes in surface inundation were predicted under an assumption of a linear surface-groundwater relationship and results will likely change under conditions where surface water – groundwater interactions do not fit this assumption. Complementary work coupling surface-groundwater interaction model outputs to ecological response models would be of benefit as it would bracket the full spectrum of risk to groundwater decline.

At the landscape scale, observation well data on water level and salinity, along with opportunistic surface water salinity records, were used to create spatial layers that predict how these values vary across the landscape. This allows for the conditions within any wetland to be predicted. Groundwater level time series data were also analysed using methods that allow a rigorous spatial analysis and statistical test of any directional change in water level – e.g. declining trends - to be undertaken. The covariance of groundwater levels with antecedent rainfall for three time windows provided an indication of spatial variations in the degree of influence of recent rainfall events on groundwater levels.

Evaluation of the new "Water Observations from Space" (WOfS) product, developed by Geoscience Australia from the Landsat satellite data archive, showed great potential for application in wetland modelling and management. The WOfS data provides a direct measure of inundation duration and also provides a means to verify predictions on wetland hydrology from other spatial methods such as interpolation of observation well data. This new data source presents many opportunities for modelling and monitoring using the hydro-salinity classification and plant functional group models. Some applications will be tested in a proof-of-concept application in the near future.

Research through this project and concurrent hydrological work suggests an exciting future for predictive wetland science in the South-East. The opportunity to couple hydrological models (Goyder SW-GW Project), downscaled regional climate projections (Charles and Fu, 2014), spatial data (particularly WOfS) with ecological response models opens an enormous range of possible investigations to support management questions. The hydro-salinity classification scheme provides a framework within which to pose, evaluate and answer questions relating to current and future wetland condition.

Regional context of the research

Surface water hydrology in the South-East NRM region of South Australia has been substantially modified from natural conditions. The construction of an extensive system of interconnected shallow channels, to facilitate the rapid drainage of seasonally high groundwater levels, has allowed high-value agricultural activities to develop. However, this has come with environmental costs and modification to wetlands resulting from changes to the natural patterns of inundation in the extensive seasonal wetland systems of the region.

Over 18,000 separate wetlands are mapped within the South-East Natural Resources Management region and they represent a major biodiversity asset for the NRM Board. Many either support threatened flora or fauna or are themselves listed as wetlands of national or international importance. Numerous studies have been undertaken over the past 20 years to assist management of these assets, though the focus has been on understanding the spatial distribution of wetlands and determining ways in which to group them for effective management.

Butcher et al. (2011) divided wetlands of the South-East into a minimum number of functional types on the basis of geomorphological, climatic, hydrological, and biotic similarities. SKM (2009) undertook a preliminary mapping of the likelihood of groundwater dependence, finding 62% of total wetland area has a high reliance on groundwater and 96% of the wetland estate has some level of dependence (SKM, 2009). Concurrent with this developing top-down understanding of regional wetland mapping and functional classification, considerable work has been undertaken into the impacts of salinity on aquatic macrophyte communities (Goodman, 2010, Goodman et al., 2010 , Aldridge et al., 2011, Goodman, 2012) and sensitivity of wetlands to groundwater decline (Cook et al., 2008, DFW, 2010). Most recently interest has turned to understanding how changes to groundwater level resulting from climate change might affect future wetland condition (Harding et al., 2015). Research reported herein is largely in response to this growing body of evidence that groundwater dependent wetlands in the region face threats from decreasing water availability and the interaction of this with salinity regimes. This project sought to assist in quantifying the magnitude of this problem. The outputs need to be considered within the context of concurrent work that has yet to be integrated, particularly the evaluation of hydrological risk to wetlands of different surface water – groundwater interaction dynamics (Goyder SW-GW project).

Historical patterns of inundation and wetland vegetation community response

The Normalised Difference Vegetation Index (NDVI) is a measure of vegetation greenness (a combination of total leaf area and per-leaf chlorophyll concentration) based on the contrast between red and near infra-red reflectance. There is a large difference in red and near infra-red reflectance for green vegetation, and a small difference for other cover types. Wetland greenness variations indicated by changes in NDVI values provide a measure of phenology (seasonal dependence in observed response). The manner in which patterns in greenness change over space and time was used as a means to determine any impact on wetlands. Time series analysis of greenness can identify periods of above or below average conditions, indicating major transitional periods at landscape scales. Clarke et al. (2015) sought to identify any trends or transitions in wetland phenology by extracting temporal greenness and inundation profiles for 20 case study wetlands in the South-East, quantifying average seasonal responses, long-term trends, and any significant breaks in those trends. This analysis indicated that the wetlands experienced reductions in greenness and inundation from 2003/04 to 2006/07, an increase in greenness and inundation until 2011 and return to lower than average conditions from 2011 to the end of 2013. This provided insights into the inter- and intra-annual pattern of inundation and greenness for the case study wetlands and the region as a whole.

Clarke et al. (2015) sought to use the greenness data in a data-driven clustering of the landscape into areas of similar temporal greenness behaviour. This allows examination of the average seasonal greenness of wetlands and other major land cover types in the South-East, identifying areas of the landscape with similar temporal greenness behaviour to known wetlands. This analysis revealed that, when looking at the landscape as a whole, the case study wetlands had a similar temporal greenness signal to the suburban areas of Mt Gambier, much of the vineyards in the Coonawarra area, some swale areas throughout the South-East, and large areas of relatively exposed soils in the north east of the study area, east of Padthaway. Examination of average seasonal greenness profiles indicated that the wetlands class is amongst the lowest; greener than coastal dune vegetation, but of lower greenness than forestry, native woody vegetation, irrigated pasture, and non-irrigated agriculture (except in summer, where non-irrigated agriculture is lower greenness).

Clarke et al. (2015) attempted to map temporal wetland inundation extent across the whole of the South-East using Landsat satellite images and a biannual sampling frequency. Images from every summer and winter from 1990 to present were included in the analysis. However, cloud cover presented clear image acquisitions in some summers, and many winters. This research still illustrated the large range of natural intra- and inter-annual variation in inundation extent over the whole South-East. In particular (Table 1) it revealed the large differences in area of inundation that can occur in wet years (e.g., 1992/93) highlighting this with the comparatively low extent of inundation occurring during the Millennium Drought years (2002 – 2008).

Table 1 Seasonal variations in inundated extent between wetter and drier years for 20 case study wetlands located across the South East region.

Year	Season	Area inundated (ha)
1992	winter	2054
1992/3	summer	1639
2007	winter	827
2006/7	summer	155

To complement these landscape scale investigations, Clarke et al. (2015) also reported on wetland scale time series vegetation community mapping. Vegetation community extents at Deadmans Swamp, The Marshes, Topperwein and Trail Waterhole were mapped using ‘heads up’ digitising, ground-truthed against current conditions. These wetlands were selected as they are known to have experienced major declines in groundwater level during the 1980s. The vegetation extent and composition for The Marshes, Topperwein and Trail Waterhole were compared between 1969 and 2013, while for Deadmans Swamp a four points in time were used: 1969, 1982, 2008 and 2013. Vegetation associations within each community were classified using the system reported in Gehrig et al. (2015), which provided a wetness ranking based on the preferred hydrological niche of the macrophyte groups. The area and type (wetting, drying or static) of all mapped changes were then analysed. There were major shifts in areal cover of wetter vegetation associations in the mapped communities from 1969, shifting to dryer vegetation communities in 2013. Relatively few changes in community were observed at Topperwein and Trail Waterholes, which provides support for their classification as being perched wetlands and therefore dependent upon local rainfall rather than surface expression of groundwater. It was also noted that concurrent increases in agroforestry occurred in the immediate vicinity of all four wetlands. This increase is likely to indirectly reduce water availability for vegetation in these wetlands through increased evapotranspiration and interception, but this analysis was unable to distinguish between the effects of changes to catchment water balance and those which may be attributable to climatic drought indicated in the inundation and greenness analysis.

Classification of wetlands and plant communities

Casanova (2011) highlights the value for water resource management purposes of grouping plant species into functional groups with consistent depth-duration preferences (Fig 2). This partitioning of hydrological niche-space allows for some level of prediction as to how the wetland plant community will be structured for a given water regime. Gehrig et al. (2015) relate the use of plant functional groups for wetland management in the South-East along with another commonly applied management-based classification: Wetland Vegetation Components (Taylor, 2006, Ecological Associates, 2009, Cooling et al., 2010). The plant functional group was used in this study as the basis for modelling wetland plant community responses to declines in groundwater level (Deane et al., 2015a, Deane et al., 2015b).

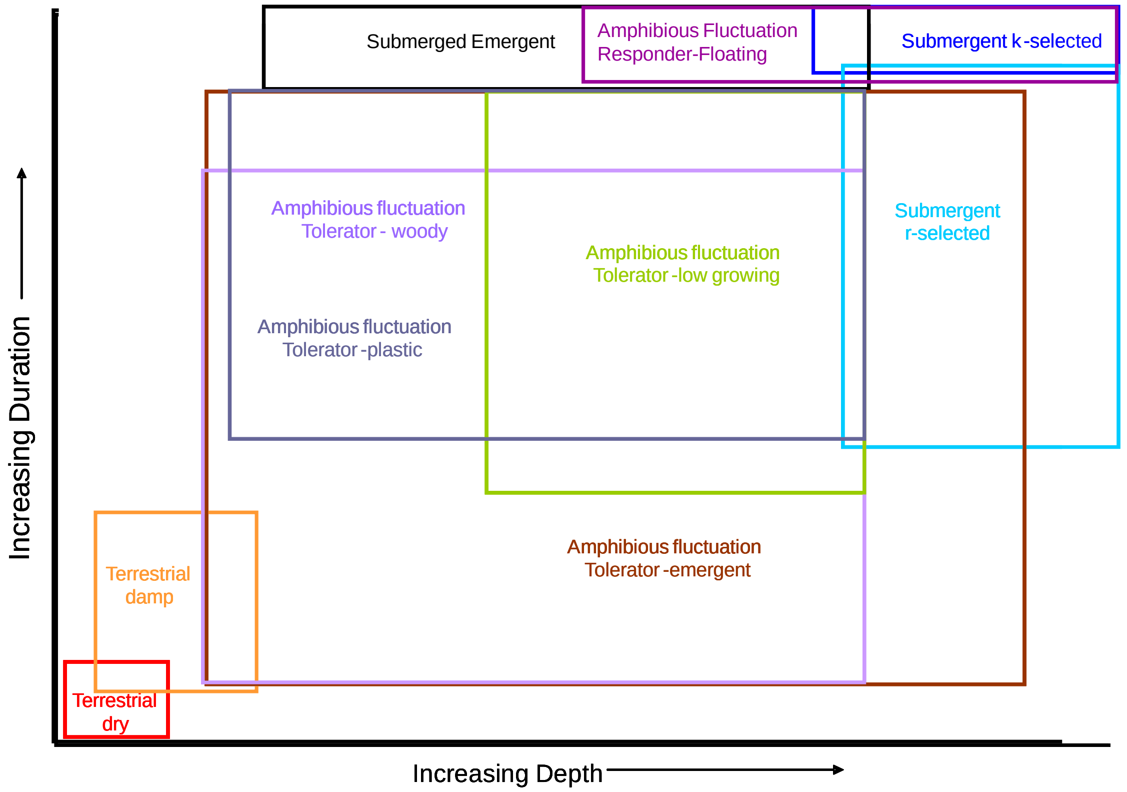

Figure 2. Plant water regime functional groups in relation to depth and duration of flooding (adapted from Casanova, 2011)

The two primary drivers of wetland plant community structure in the South-East region are considered to be hydrology (Taylor, 2006, Ecological Associates, 2009, Cooling et al., 2010) and salinity (Goodman, 2010, Goodman et al., 2010 , Aldridge et al., 2011, Goodman, 2012). Gehrig et al. (2015) develop a classification system based on these two environmental variables, adopting three classes for each, in order to develop a straightforward means to map wetlands or wetland habitat into a two-dimensional hydro-salinity space (Fig 3). This provides a versatile means to group similar wetland habitat at any scale of interest and if linked with remote sensing and geostatistical modelling has potential for application at regional scales (see Turner et al., 2015, for some examples).

The hydrological axis (horizontal axis in Fig. 3) has three classes ranging from permanently inundated to never inundated (based largely on Semeniuk and Semeniuk, 1995), while salinity is subdivided into categories of fresh, brackish or saline largely following Cowardin et al. (1979) and Butcher et al. (2011). Wetlands vary in salinity concentrations both seasonally and inter-annually. Where different classes would result, they are characterised by the salinity in which the wetland exists for the major part of the year (or inundation period).

Therefore, by combining the hydrology and salinity (hydroperiod × salinity) classes, nine primary types of wetlands or wetland habitats are predicted: Permanent Fresh (e.g. Pick Swamp), Seasonal Fresh (e.g. Trail Waterhole, Topperwein, The Marshes, Hacks Lagoon), Ephemeral Fresh (e.g. Deadmans Swamp), Permanent Brackish, Seasonal Brackish (e.g. Taratap, Lake Hawdon South, Middlepoint Swamp), Ephemeral Brackish, Permanent Saline (e.g. Big and Middle lakes (Lake George), Robe Lake, Big Dip Lake), Seasonal Saline (e.g. Small Lake,at the Lake George complex) and Ephemeral Saline.

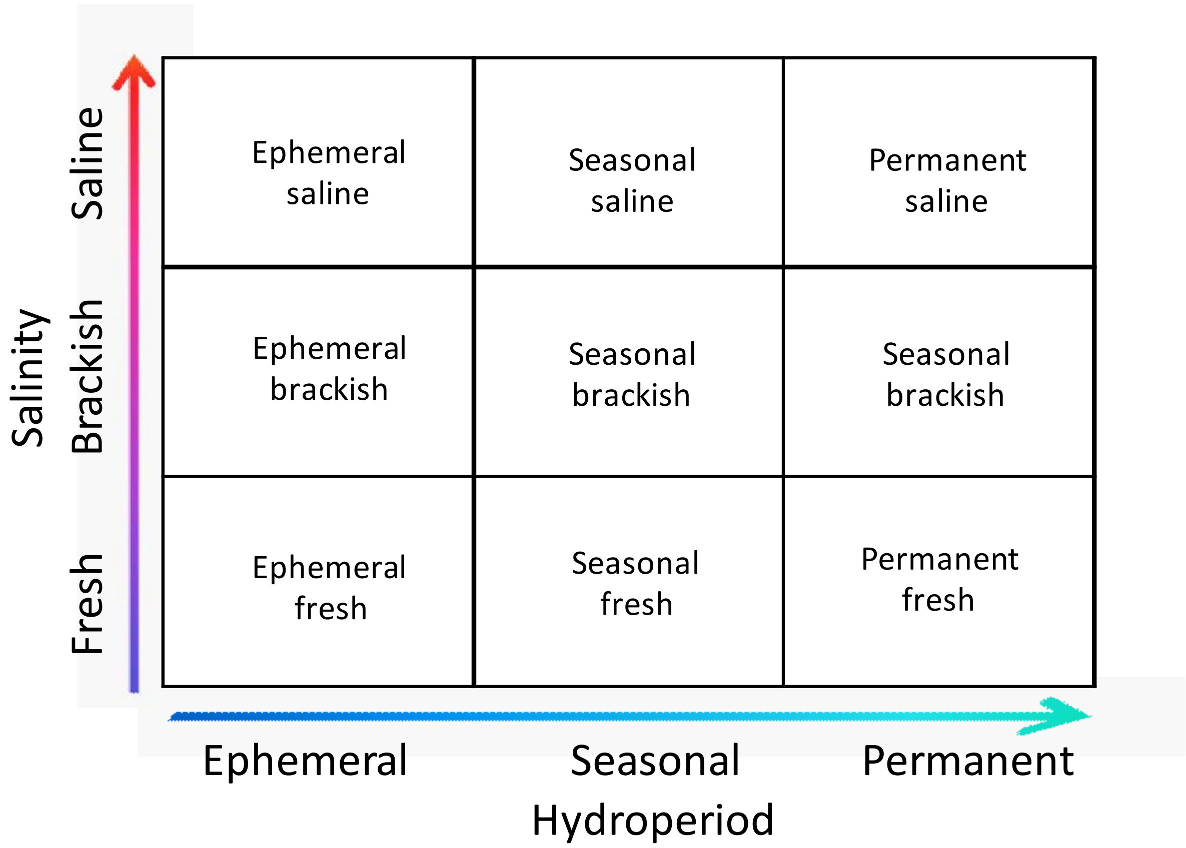

Figure 3. Classification framework for South-East wetland types combining hydroperiod and salinity. Axes indicate variation in hydrology (horizontal axis, increasing values indicate increasing permanence of inundation), and salinity (vertical axis, increasing values indicate higher levels of salinity). Wetland habitat at any desired scale can be mapped into this hydro-salinity space, providing a means to group habitats predicted to support similar flora and fauna.

Study design and field data collection

Gehrig et al. (2015) report on the theoretical basis informing development of the field sampling program. The aims of sampling were to identify the distribution of the different plant functional groups at wetlands and in this way sample from conditions representing the range of natural variability. A set of case study sites from within the 20 wetland complexes with monitoring data available were selected that best represent the range of hydrological, water quality, and geomorphic settings. These wetlands encompass the majority of the nine theoretical wetland types described by the regional classification framework. In total 12 wetlands, comprising 28 different basins were sampled from the SE NRM Board groundwater dependent ecosystem monitoring network. These case study wetlands were: Deadmans Swamp, The Marshes, Trail Waterhole, Topperwein, Lake Hawdon South, Bool/Hacks Lagoon, Lake Robe, Big Dip Lake, Middlepoint Swamp, Pick Swamp, Lake George and Taratap.

At the selected case study sites, field surveys were undertaken to:

- assess the salinity and water regime preferences of plant species/functional groups;
- evaluate regional classification frameworks;
- validate and ground truth remotely sensed data; and,
- guide the development of eco-hydrological conceptual models for wetland types.

Vegetation data were collected from sites where hydrological monitoring data were also available, providing a record of water level variations for the antecedent period four years prior to vegetation sampling. The water regime at each vegetation sampling location was related to the hydrological monitoring data by estimating elevation using the regional 2 m digital elevation model. These estimates were verified and where necessary corrected against observed depths during the Spring 2013 sampling round. The observed water level hydrograph was modified to represent variations in water level for each vegetation sampling location, with four summary variables determined that represented the conditions for the antecedent period.

Modelling wetland response to changes in hydrology

Predicting plant functional group responses to water regime

The wetland flora data from the 12 case study wetlands was used to develop hydrological response curves for the most common wetland plant functional groups (PFG). The hydrological niche models were built, and their predictive capability validated, using the combined vegetation and hydrological data from the wetlands (Deane et al., 2015b). A multimodel inferential framework (Burnham and Anderson, 2002) was used to construct models for eight plant functional group types, which tested 20 competing hypotheses for each group relating to biologically plausible water regime responses. Model averaged predictive models were built using the weight of evidence for each hypothesis. Model structure reveals the most reliable water regime variable to predict the presence of each functional group and the manner in which the group responds (Fig. 4).

Models were constructed using generalised linear mixed models, allowing the incorporation of both fixed and random effects within the model structures. Random intercepts were used to cope with intra-site spatial autocorrelation in model residuals (a violation of model assumptions), while random slopes were added in order to provide a more general level of inference that reflects a population level response.

Three classes of response were observed, with ecotone species generally conforming to a linearly decreasing function of inundation magnitude, the wettest group (Se submerged emergent) exhibiting a response that increased with water regime and intermediate groups having a unimodal (hump-shaped) response curves with slightly staggered modes (preferred depths) in the middle of the observed range of water regimes (Fig 4).

The predictive hydrological variable that explained the most variation was the sum exceedance value at ground level (SEV0); an integrated measure of depth and duration response analogous to degree-days. This value is calculated by adding the depths above a threshold together producing a single value representing the total annual depth and duration. The same SEV0 value of 1 m.d then would be returned for different possible combinations: 1 m depth of water for only one day, a 0.5 m depth for 2 days or a 0.2 m depth for five days and so on. Maximum inundation depth was also important for multiple groups, while hydroperiod and depth to groundwater explained less variation. Salinity (as electrical conductivity) was also confirmed as an important predictor of the prevalence in the majority of plant functional groups (PFG). Higher salinity classes were generally associated with decreased prevalence, although Sr - submerged r-selected plants (e.g. Ruppia spp. see Deane et al., 2015b, supplementary material) were most abundant at the highest salinity wetlands. The value of water regime variables for the mode in response (highest predicted probability of being present) was generally consistent across salinity classes (Fig. 4).

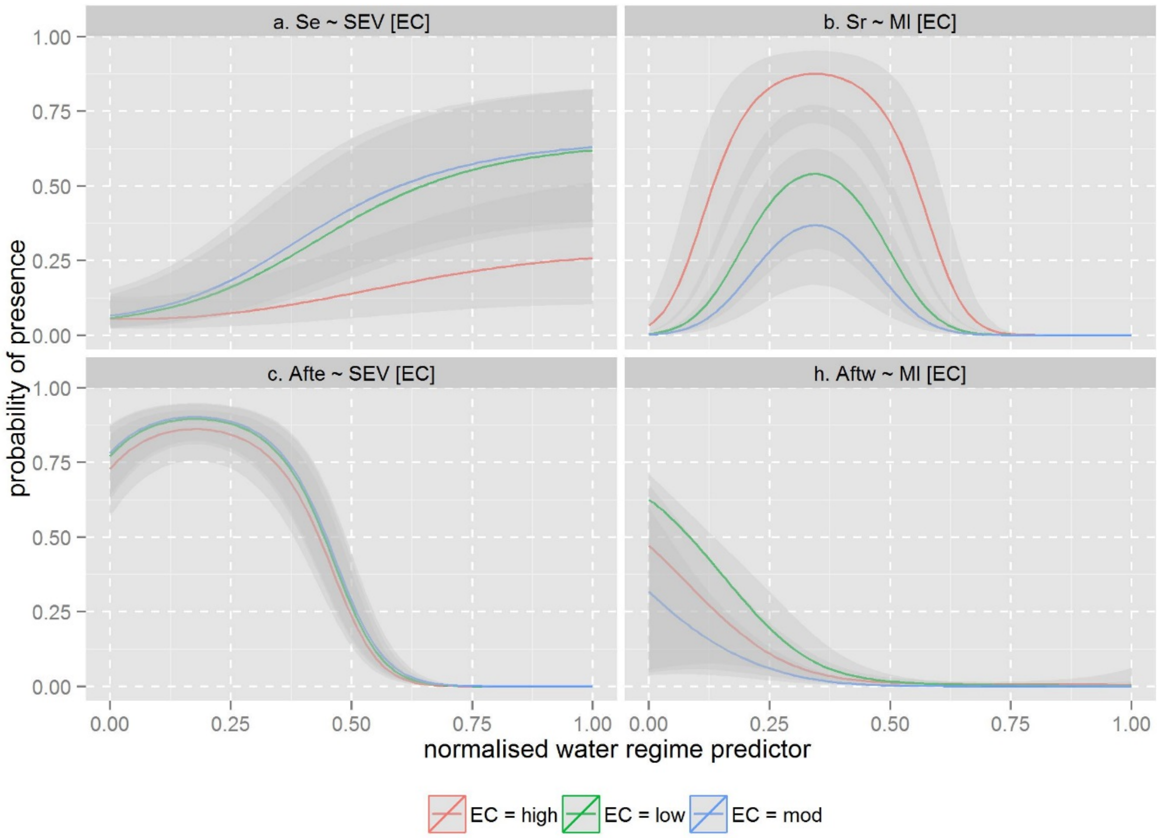

Figure 4 Plant functional group response curves under three salinity classes (low, moderate and high) indicated by line colour. The water regime variable on the x-axis is indicated by the formula (SEV = sum exceedance value; MI = maximum inundation). Shown are examples of the three main patterns observed (a) Plant functional group 'Submerged emergent' (Se) shows a monotonically increasing response to water regime and was best described by sum exceedance value at ground level and has very low prevalence at high salinities; (b) 'Submerged r-selected' (Sr) and (c) 'Amphibious fluctuation tolerator emergent' (Afte) were unimodal (hump-shaped) functions, best explained by maximum depth of inundation (MI) and SEV respectively. Sr was most prevalent at high salinity sites, while Afte prevalence was not affected by salinity; (d) 'Amphibious fluctuation tolerator woody' (Aftw) was best explained as a decreasing function of maximum inundation depth. Shading indicates 95% confidence intervals on the mean response.

Diagnostic power varied across the models, with PFG at the extremes of the wetness gradient (submerged species, ecotone species – Aftw, Tdamp) predicted more successfully than those occupying intermediate areas of niche space (e.g. Afte, Afrp). The correct classification rate averaged 83% across all functional group and the species distribution model diagnostic metric, AUC (area under the receiver operator characteristic curve), varied from 0.76 to 0.99, indicating good to excellent performance in correctly predicting the presence of functional groups. Prediction accuracy was generally greater at the extremes of water preference as models needed to discriminate between fewer PFG.

Past work in the region has concentrated on establishing salinity tolerances at the species (Goodman et al., 2010 , Goodman, 2012) and Wetland Vegetation Component levels (WVC; Taylor, 2006, Cooling et al., 2010) . This provides guidance on suitable thresholds for managing wetland plant communities only at these levels of organisation. For example, if maintaining the proportional cover of one or a few dominant species or WVC vegetation cover was a management goal, salinity levels can be based on relevant thresholds. Salinity classes in the PFG models provide an indication of the relative prevalence of each functional group within that class, but provide no indication of critical salinity tolerances within a functional group; the models can provide guidance for hydrological regime management which applies to a given PFG regardless of salinity class. This is a result of the hydrological basis in which PFG are defined. In fact inundation and salinity interact strongly and the individual contributions these make to wetland communities is difficult to determine. For setting risk levels associated with salinity, it may be possible to extend the thresholds in Goodman (2010) by seeking break points or inflections in major macroecological patterns more appropriate to the community level of organisation. Species abundance distributions, species area relationships, or distance-decay in community similarity (where 'distance' here is defined by a measure of salinity) all provide insights into biological processes that may exhibit a salinity response. Any such threshold developed could, in a manner that is analogous to PFG, be applied independent of vegetation identity increasing its generality. Wetland managers and policy makers at landscape-scales may be well served by models that sought thresholds in response to salinity for these to complement existing empirical classifications and PFG models.

Predicted responses to drawdown at the wetland scale

Water allocation plans for the South-East specify maximum levels of decline that are permissible to ensure connections between groundwater dependent ecosystems (GDE) and the unconfined aquifer are maintained. Thresholds triggering management intervention in groundwater systems supporting designated 'high value' and other GDE are -0.05 and -0.1 $m.yr^{-1}$ respectively, measured over the previous five years. Deane et al. (2015a) used the response curves described above and water allocation plan thresholds as the basis for modelling impacts on GDE plant communities following groundwater drawdown. Modelled scenarios were: 0 m (baseline); 0.25 m; 0.5 m; and 1 m.

Responses were investigated for two generalised wetland bathymetries typical of the Grass Sedge and Inland Interdunal typologies of Butcher et al. (2011). Grass Sedge wetlands have a relatively shallow profile and more complex geometry, while Inland Interdunal wetlands are deeper and tend to a more circular geometry. These are among the most abundant wetland types with a high likelihood of groundwater dependence in the region (SKM, 2009) and together these bathymetries encompass the range of variability of around 75% of wetlands of interest to regional water allocation planners in the South-East. Model systems reflected the size and depth distribution of the two typologies: a small, irregularly shaped (~ 5 ha) shallow basin represented Grass Sedge wetlands (average depth ~ 0.5 m, maximum depth 0.8 m), and a roughly circular, large (~15 ha) and deeper (average depth ~0.8 m, maximum depth ~1 m) profile represented deflation basin typical of Inland Interdunal wetland types. Detailed description of the derivation of the scenario bathymetries can be found in the Supplementary Material for Deane et al. (2015a).

An empirical linear relationship between groundwater and surface water levels was used to predict changes in wetland hydrology for a decline in groundwater level. The slope of the relationship was 0.66 (R2 = 0.91) and consistent with other similar work at other sites in the South-East (Harding et al., 2015). The linear relationship was used to predict the reduction in surface water that would be observed by declines in groundwater level according to each scenario (0.25, 0.5 and 1.0 m).

The probability of observing each functional group at each point in the hypothetical wetlands was determined using the response curves in Deane et al. (2015b) for 'moderate' salinity levels as this is most representative of the wetland types of interest. For each scenario and wetland bathymetry results of the binary (present/absent) prediction for each wetland was calculated. Findings were reported as the % cover of each functional group within each wetland-scenario combination, with graphical summaries of the shared distribution of PFG that results (e.g. Fig 5). The Supplementary Material for Deane et al. (2015a) presents PFG distribution maps for every scenario, providing maps of raw prediction probabilities, presence-absence of PFG and uncertainty for each.

Model uncertainty was determined by comparing the probability used to predict the assigned state of present or absent with the theoretical maximum possible probability. As some scenarios exceeding a 0.25 m drawdown required extrapolation of the response curves, a penalty term was introduced where model uncertainty was increased by a factor of 2. Model uncertainty was low in the current and 0.25 m scenario, but increased greatly in the 0.5 m and, in particular, 1.0 m scenarios.

Modelled outputs indicated that the sensitivity to groundwater decline depends on bathymetry, but both wetlands types were predicted to experience major changes in zonation and loss of multiple functional groups if the mean depth to groundwater declines by 1.0 m. Modelling suggests shallow Grass Sedge wetland types may be able to sustain a 0.25 m decline with minimal ecological impacts, but any greater decline in level would place them at risk of the loss of at least one functional group. Predictions for the deeper Inland Interdunal wetlands indicated a 0.5 m decline may have limited impact, but by the time declines reached 1.0 m loss of functional groups and major structural changes would occur. It needs to be recognised that modelling predicts only the result of changes in water level, assuming salinity remains within moderate levels. However, major increases in salinity in wetland soil profiles will likely occur concurrent with groundwater decline and this may have an interactive effect at the species level (Goodman et al., 2010 , Goodman, 2012). This work also assumes only a single, linear relationship between wetland surface water levels and groundwater, but wetlands are known to vary greatly in these characteristics (Goyder SW-GW project). These predictions will only have relevance for wetlands with a comparable surface - groundwater interaction dynamic to that assumed in developing the scenarios.

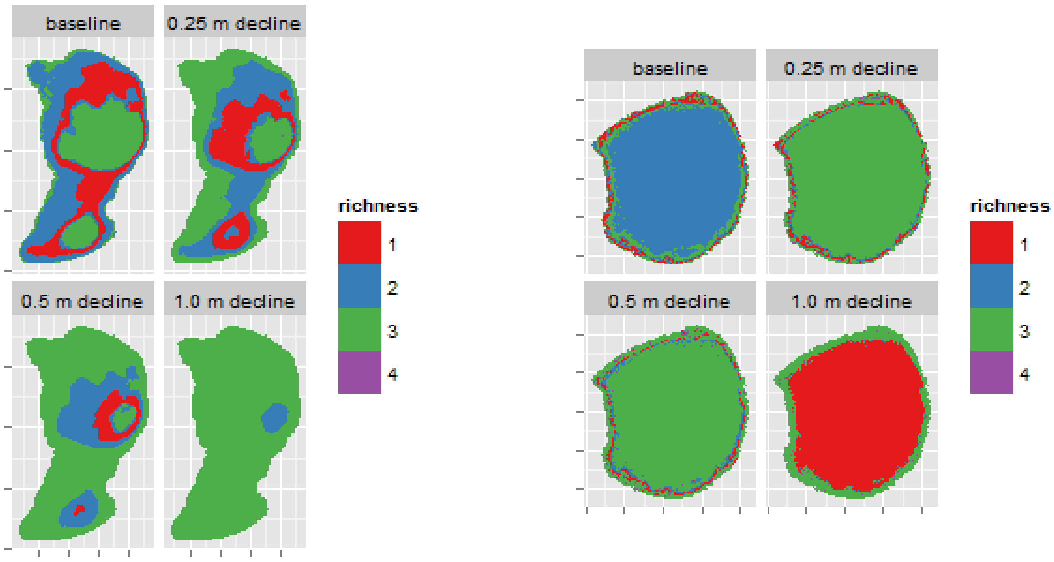

Figure 5 Modelled plant functional group richness for the two wetland bathymetries and four water level scenarios in Deane et al 2015. The shallow wetland (left series of panels) is seriously impacted for declines exceeding 0.25 m and at a 1.0 m decline would be almost unrecognisable as a wetland. The deeper, Inland Interdunal wetland type (right series of panels) initially increases in richness with an additional submerged species being favoured but remains fairly unaffected by drawdowns up to 0.5 m. Between a 0.5 and 1.0 m decline the two submerged groups are lost and the wetland core is predicted to instead by covered by Afte a plant functional group consisting largely of sedges.

Landscape-scale inundation patterns and wetland distribution

For effective wetland management at regional scales it is important that the spatial distribution and variability in wetland extent and condition are understood. Turner et al. (2015) compiled an extensive spatial database for the South-East (detailed in Gehrig et al., 2015) and used this to interpolate landscape scale patterns of groundwater level and salinity across the region. This makes it possible to estimate the hydrology or salinity conditions at any point in the landscape. By linking this spatial modelling to point observations from within wetlands the accuracy of predictions can be determined. Moreover the new "Water Observations from Space" (WOfS) product, developed by Geoscience Australia from the Landsat satellite data archive, allows predictions to be verified with observed data and allows many other useful applications that will be tested in a proof-of-concept application.

Turner et al. (2015) compiled a large amount of groundwater level and salinity data from regional observation monitoring wells. Trends in groundwater level since 1990, and how these are affected by antecedent cumulative rainfall, were examined using this database. Spatial patterns of salinity in both surface water and groundwater were interpolated, then categorised to reflect the classification framework for wetland types presented in Gehrig et al. (2015). Finally, the location of 13 selected surveyed flora species were mapped and compared with the new regional wetland classification framework.

The WOfS data can provide new insights into the inundation regime of all the wetlands in the South-East (Fig 6a and b) and has the potential to define wetland inundation at 25 m resolution. This can then be used to validate and or update the South Australian Wetland Inventory Database (SAWID) classification of water regime. It can also be used to classify many wetland polygons which are not currently classified in SAWID. The data can then be used to model scenarios of changed inundation patterns. Turner et al. (2015) also identified a number of shortcomings with the WOfS data, which has contributed to the development of the product and are now being rectified. Once these issues are resolved, scenario modelling on a landscape scale using the wetland type and functional group classification conceptual models, will be possible and the improved results submitted as a journal paper.

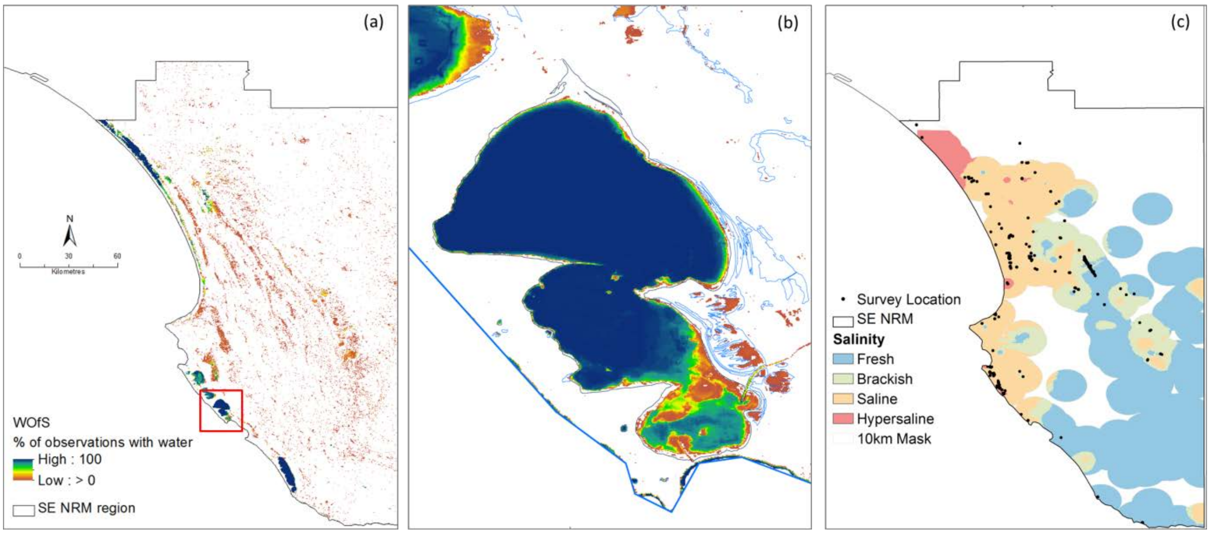

Figure 6. Example of some landscape modelling outputs from (a) WOfS inundation 1987-2014 for the SE NRM region (b) Close up of WOfS for Lake George – extent shown by the red rectangle in panel a (c) Interpolated surface water salinity (with areas greater than 10 km from salinity observation points masked) and Sarcocornia quinqueflora survey locations

The majority of wetlands in the South-East are known to have a dependence on groundwater. Although DEWNR has been monitoring and mapping changes in groundwater levels for many years, very little data are available from within wetlands themselves. Turner et al. (2015) presents a method which allows a rigorous spatial analysis of water level trends and to which statistical methods can be applied to identify non-random patterns in level variation. Turner et al. (2015) also established relationships with antecedent rainfall (annual, monthly and daily) on a regional basis, providing an indication of spatial variations in the degree of influence of recent rainfall events on groundwater levels. This can be useful for modelling, for example, using downscaled climate projections to determine the potential impacts on wetlands. The interpolated surface water salinity (EC) surface, although based on relatively few readings, generally matches the overall trends of the interpolated mean groundwater salinity surface. This allows for comparison of the observed species distributions against predicted salinity ranges, which can be used to verify the predictions of the interpolated surface, or identify any systematic variations from these potentially further improving our process understanding. In locations where predictions can be independently verified, these surfaces also provide a means to obtain additional information on the salinity conditions experienced by different species present and may help to refine our understanding of salinity tolerance.

Using the hydro-salinity classification provides a means to map the area of each habitat type for each wetland, particularly if this can be effectively coupled to the WOfS data. Among the uses might be an estimate of the dominant hydroperiod (ephemeral, seasonal or permanent) and salinity (fresh, brackish or saline) for all wetlands that could be incorporated into SAWID. As it is now possible to classify the different wetland 'habitats' that we would expect to find within a wetland for a given set of hydro-salinity conditions, these habitat classes can be determined on a (25 m x 25 m) cell by cell basis. Within each wetland there may be a number of quite distinct areas (such as a freshwater spring within a permanently salty lake, or wetlands with some areas of permanent inundation and other less frequently inundated areas). If these can be mapped remotely, this classification provides a means to determine wetland habitat complexity (as determined by the number of different classes represented) and to track this over time (as determined by the number of cells falling within each class).

A wetland diversity scoring system that incorporates functional group, wetland vegetation component or species diversity could be developed and applied at wetland scale. Such a classification system could also be used for wetland condition monitoring over time or for modelling various scenarios. Projections based on changes in hydrology and/or salinity could be modelled in a straightforward manner using WOfS (and will be demonstrated in a proof-of-concept study once the revised version of the data are available). This could be as simple as calculating the change in area (e.g. hectares) and location of each wetland hydro-salinity classification category, given different scenarios with the total area of each expected habitat modelled for the entire region or any subset of it.

With the availability of the new Regional Water Balance Model and Climate Change Projections, developed by the Goyder Institute for the South-East, along with the relationships and mechanisms identified in this project for surface inundation, groundwater levels and rainfall, it will be possible to develop more sophisticated models capable of testing useful change scenarios. Other datasets, such as soil, land use, the drainage network and groundwater extraction rates could also potentially be incorporated. The hydro-salinity classification can differentiate habitat types within and between wetlands making it possible to extrapolate the distribution of wetland habitat to any other area or region where there is a reasonable estimate of the hydro-salinity dynamics. This would then allow the development of sensible predictions on community composition likely to be present in those areas.

Appendices

Appendix 1 - Contributed project reports and draft manuscripts

The project was divided into a number of discrete investigations with varying degrees of integration. Work under each research task is reported independently as follows:

Task 1 report (Gehrig et al., 2015) – reports on the following:

- baseline data sources
- development of a wetland classification system based on the assignment of common aquatic plant species for the region into hydrology (plant functional groups) and salinity tolerance classes
- design aspect of the conceptual modelling work including case study selection and survey design

Task 2 the process of selecting sites and undertaking field sampling is reported in Gehrig et al. (2015)

Task 3 employed remote sensing techniques with the aim of improving understanding of the historic temporal patterns in inundation and corresponding behaviour of wetland vegetation, and to determine whether there have been changes in wetlands in the South-East over recent decades. There are three components, reported in Clarke et al. (2015):

- landscape scale trends in wetland phenology (greenness) and inundation
- time series comparison of inundation extent at 20 case study wetlands
- detailed mapping of changes in vegetation communities between 1969 and 2013 for four wetlands

Task 4 involved the development of conceptual models of wetland plants reported in the Task 1 report. Complementary work was also undertaken to extend this to quantitative predictive models reported in Deane et al. (2015b). These models were used to predict the consequences of water level drawdown at wetland scale for two hypothetical bathymetries, which is reported in Deane et al. (2015a).

Task 5 aimed to investigate spatial relationships at the regional scale, developing a wetland GIS model for the South-East Natural Resource Management (SE NRM) region integrating relevant available data. Turner et al. (2015) reports on the findings:

- application of the wetland classification conceptual models (Gehrig et al., 2015) to a landscape scale, identifying wetlands with similar ecological response to water regimes (water quantity and salinity) and species distributions according to predicted salinity and inundation
- spatial relationships between regional groundwater conditions and wetland water requirements based on a conceptual understanding of water requirements and historical inundation extents
- a proof-of-concept application of the new Geoscience Australia spatial product ‘Water observations from space’ for wetland hydrological analysis

Task 6 was the integration of findings into a cohesive single reference (this document).

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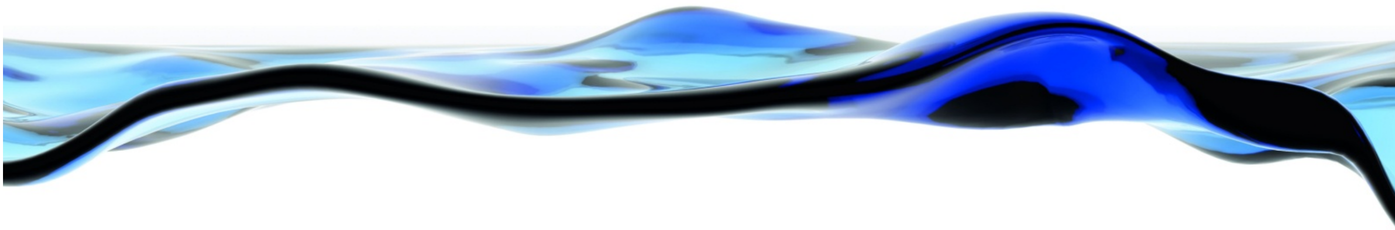

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