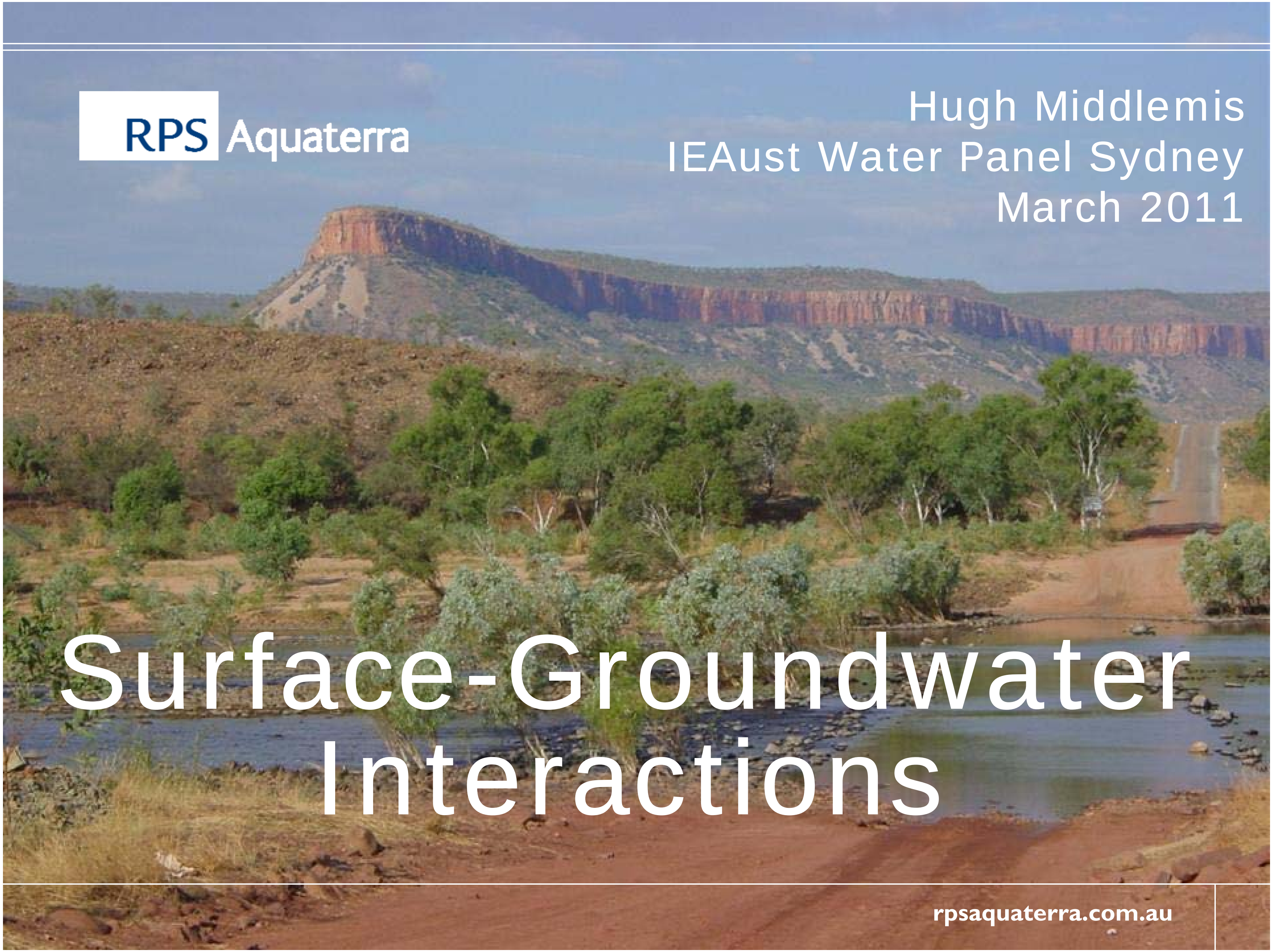


RPS Aquaterra

Hugh Middlemis
IEAust Water Panel Sydney
March 2011

Surface-Groundwater Interactions

Outline

- Premise & General Principles
- Concepts & Definitions
- Connectivity Issues & Misconceptions
- Dynamic Processes & Conjunctive Mgt
- Integrated Modelling Future
- Floodplain process case study (GW)
- Mike-SHE case study (fully integrated)

Acknowledgements

- Glenn Passfield ~ RPS Aquaterra
- Terry van Kalken ~ DHI
- Rick Evans, Ray Evans, Stuart Richardson ~ SKM
- Ian Jolly ~ CSIRO / eWater
- Joel Hall ~ WA Dept of Water

- Winter et al 1998: http://pubs.usgs.gov/circ/circ1139/#pdf
- www.**connectedwater**.gov.au
- www.**connectedwaters**.unsw.edu.au
- Mallee CMA, Tas DPIPWE, CSIRO, SKM
- Water Technology ~ www.watech.com.au

Premise

- Best practice involves:
  - defined purpose
    - quick-cheap-good (enough) paradox
  - sound concepts, data and models
- Is current practice good enough?
- Critical/Constructive comments in this talk
- Acknowledge that some very good progress is being made
- Concern about overtrumping of:
  - hydraulics by hydrology?
  - groundwater by surface water?

Hydroschizophrenia

- separate management of surface and groundwater
- playing down the role of groundwater
- poor and uncoordinated transboundary groundwater management

- Jarvis et al. 2005; Llamas and Martinez-Santos 2005; cited in Tomlinson and Boulton, 2008 (NWC Waterlines no.8 on GDEs)

General Principles

- Groundwater and surface water are actually interconnected and interchangeable
  - GW becomes SW, and SW becomes GW
- Not recognised due to long time lags on processes (typically years to decades)
- Non-integrated analysis & management results in double accounting/allocation
- In some parts of Australia we have capped SW, but can still drill a bore near the banks of a river and call it GW and get it licensed

General Principles

- Virtually complete absence of integrated SW-GW management across Australia (see NWC Baseline Assessment Project, Stage 1)

- Biennial Assessment 2009:
  "*The National Water Commission considers that unless and until it can be demonstrated otherwise, surface water and groundwater resources should be assumed to be connected, and water planning and management of the resources should be conjunctive. This is the reverse of the current situation.*"

Integration -> Balance?

Surface Water	Groundwater
High volumes & flows, but evap. problem on storages	Low flow rates, but high volumes in storage & no evap.
Quick hydrological response, no time lags	Slow hydrological response, long time lag
Usually lower salinity	Often higher salinity
In-stream & floodplain ecosystem complex but measurable	GDEs: Groundwater Dependent Ecosystems - hidden dependencies

Methods (1/2)

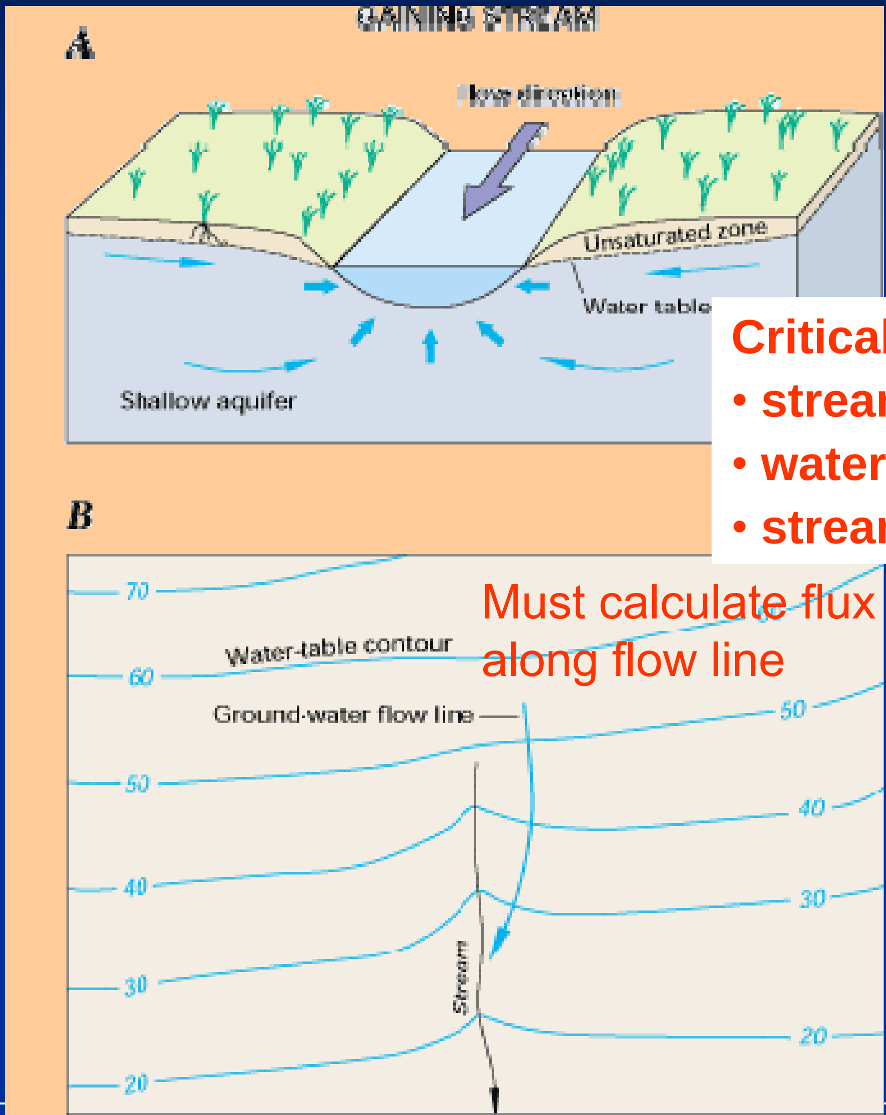
- Gauged Stream Flow analysis
  - Base Flow Index (BFI) via digital recursive filters
- Groundwater monitoring bores
  - GWL responses to stream flow & rainfall events
  - GWL-CRD plots (cumulative rainfall deviation from mean)
  - Horizontal flow directions (to/from stream)
  - Multi-level piezometers to measure vertical hydraulic gradients near surface water bodies
- Connectivity mapping (more later)
  - Use bores within 1 km from rivers
  - Direction of flux (should be along GW flowline)
  - Magnitude of flux (Darcian approach)

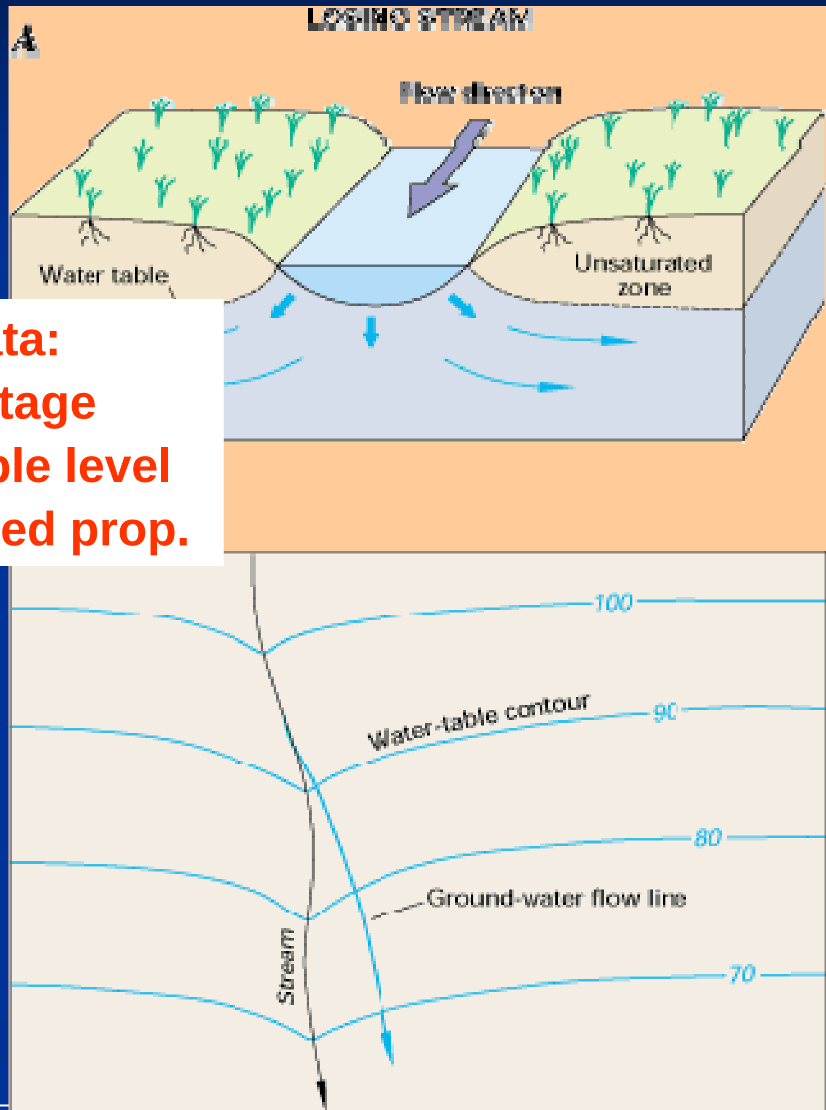
Methods 2 / 2

- Thermal survey (groundwater warmer)
- Airborne EM (electro-magnetic)
- In-stream nanoTEM and conductivity meters
- Groundwater flow modelling
- Mass-balance modelling (water, solutes, stable isotopes) to estimate GW flows
- Geochemical analysis
  - Isotope analysis (vertical and lateral recharge)
  - Chloride mass balance

Saturated hydraulic connection

Gaining Stream — Losing Stream



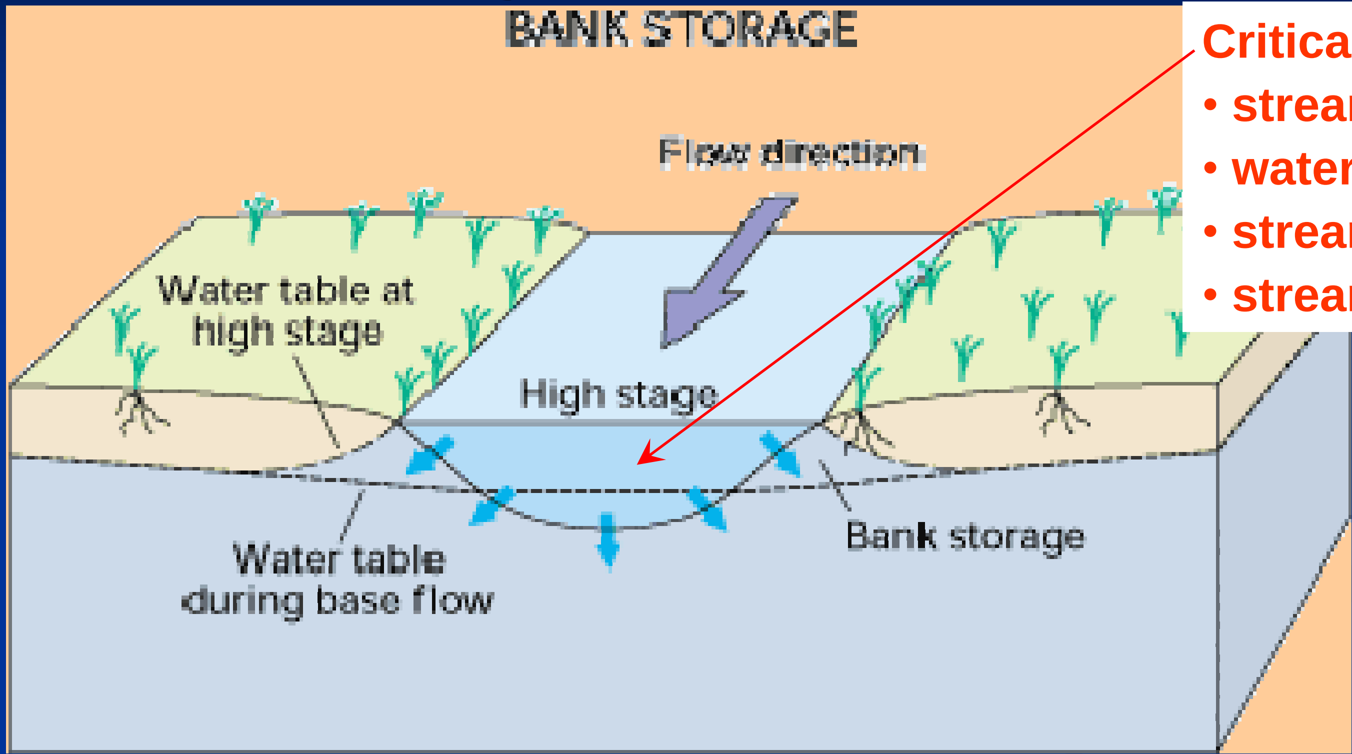


Critical data:

- **stream stage**
- **water table level**
- **stream bed prop.**

Must calculate flux along flow line

Variably Gaining/Losing (saturated hydraulic connection)



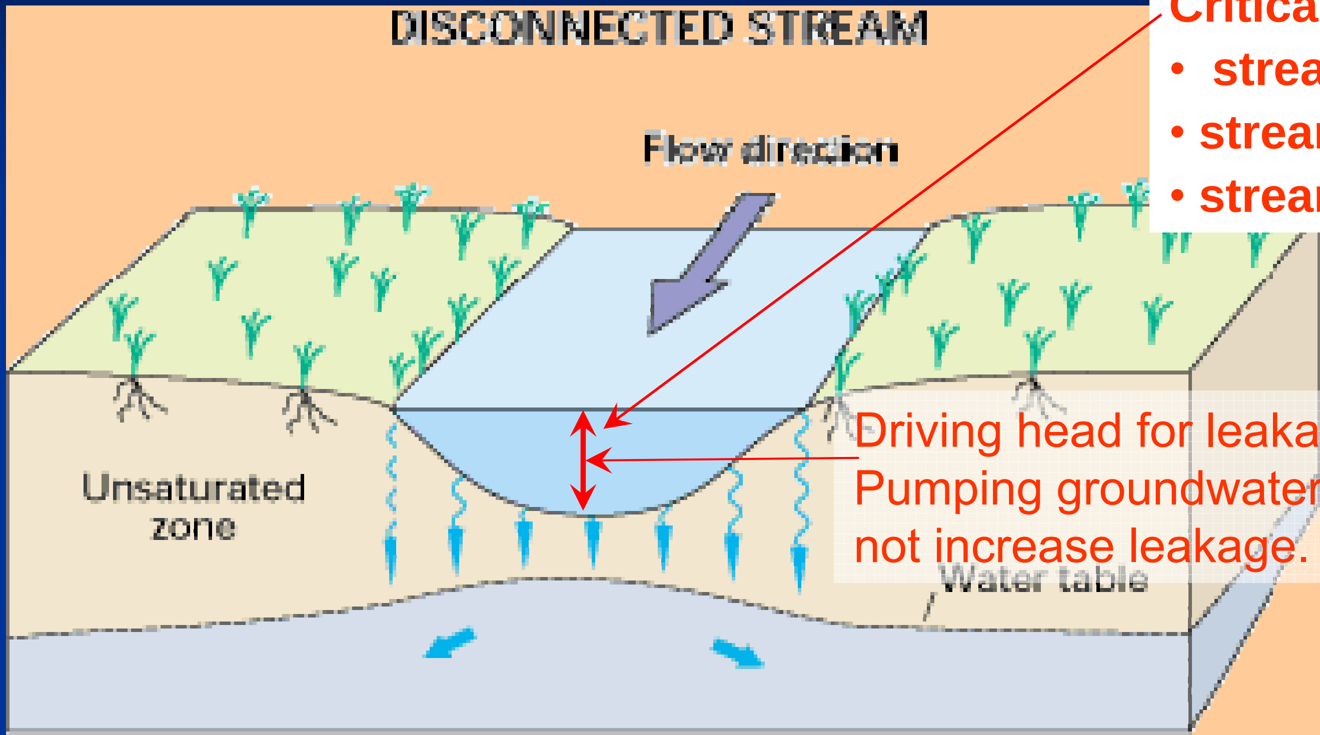
Critical data:
- **stream stage**
- **water table level**
- **stream bed prop.**
- **stream bed level**

Losing stream for high river stage (low water table)

Gaining stream for low river stage (high water table)

Many stream reaches are variable & dynamic with time

Disconnected… NOT!
Losing-Unsaturated or Max/Perched-Losing



Critical data:
- stream stage
- stream bed prop.
- stream bed level

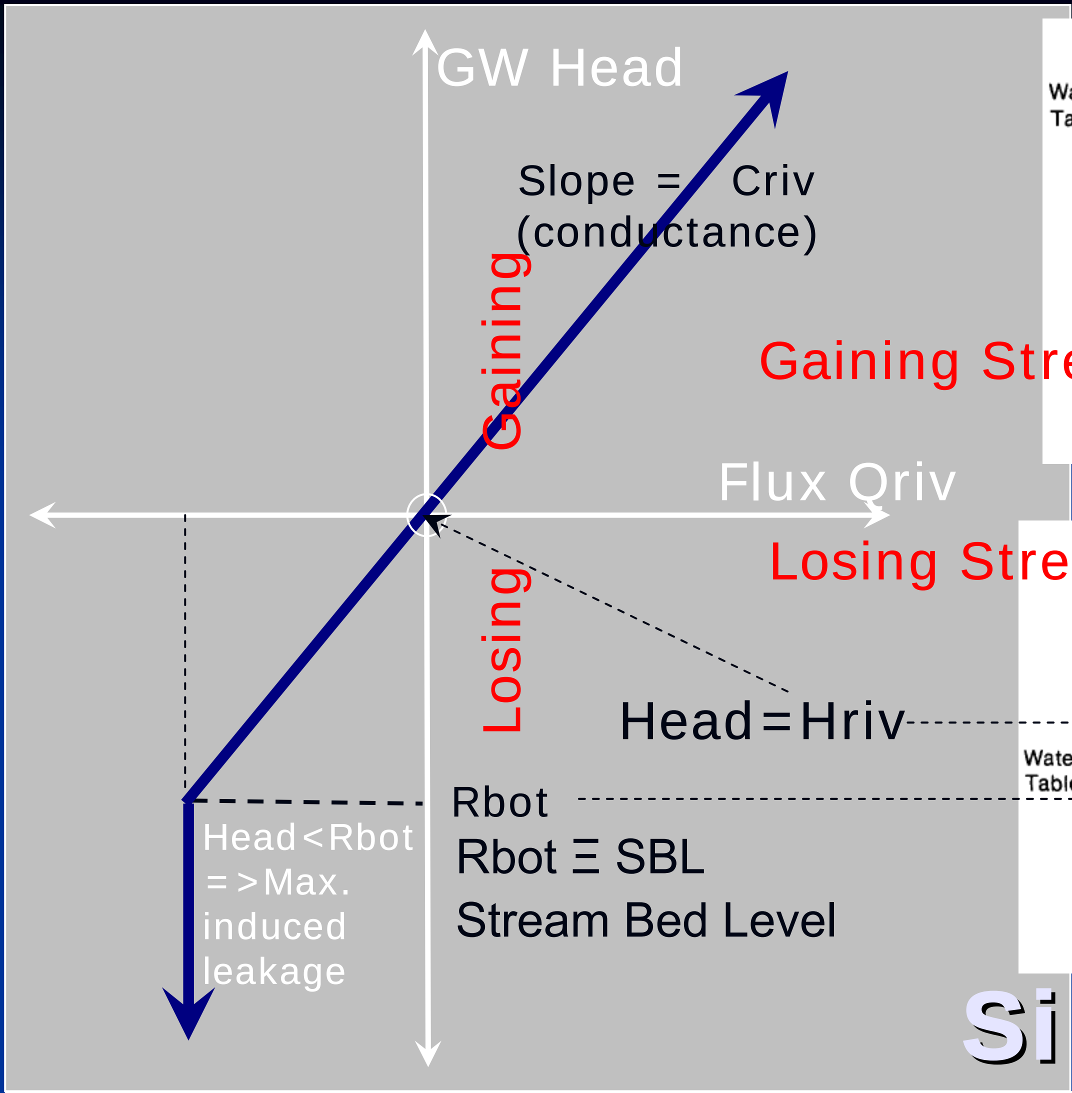
Driving head for leakage. Pumping groundwater will not increase leakage.

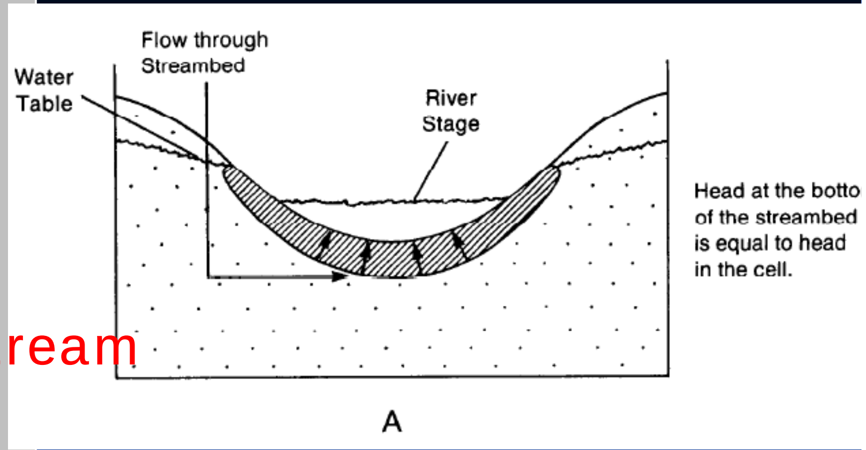
Cannot be disconnected when there is leakage/mounding, however small.

Stream is **losing**, and at maximum potential rate through **unsaturated** zone (provided reasonable separation of water table below stream bed).

GW pumping may not increase leakage locally, but can increase length of losing reach.

Simple saturated flow model (Modflow)





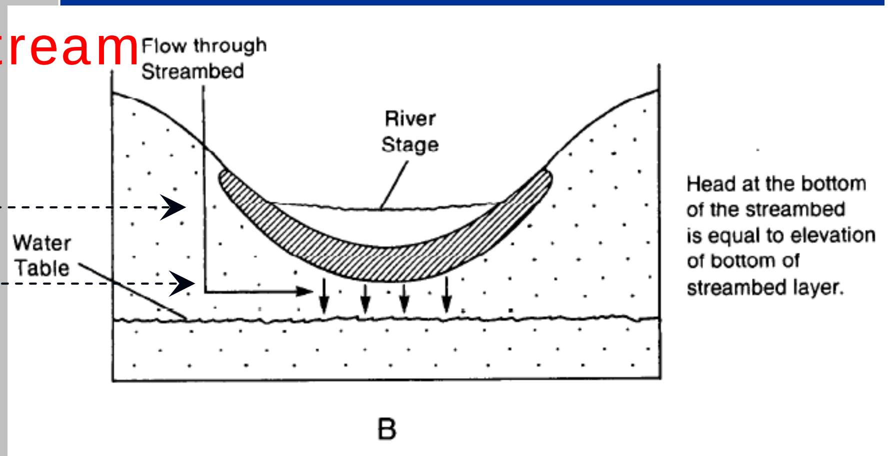


Figure 36.—Plot of flow, QRIV, from a stream into a cell as a function of head, h, in the cell where RBOT is the elevation of the bottom of the streambed and HRIV is the head in the stream.

Stream-Aquifer Connectivity

GWL = groundwater level… critical data
SBL = stream bed level… critical data

Rassam *et al*, (2008)

GWL and SBL	Hydraulic connection	Classification	Type of connection	Flux
GWL above SBL*	Saturated	Gaining	Gaining; stream gaining water (baseflow) from groundwater	Depends on head difference and streambed conductance
		Losing	Losing; stream losing water to groundwater	
GWL slightly below SBL	Saturated	Losing	Losing	Depends on thickness of clogging layer, relative conductivities of clogging layer and aquifer material, depth to watertable, and stream width; flux increases until it reaches a status of maximum loss
GWL below SBL	Unsaturated	Losing		
GWL well below SBL	Unsaturated, maximum loss flux	Max Losing		

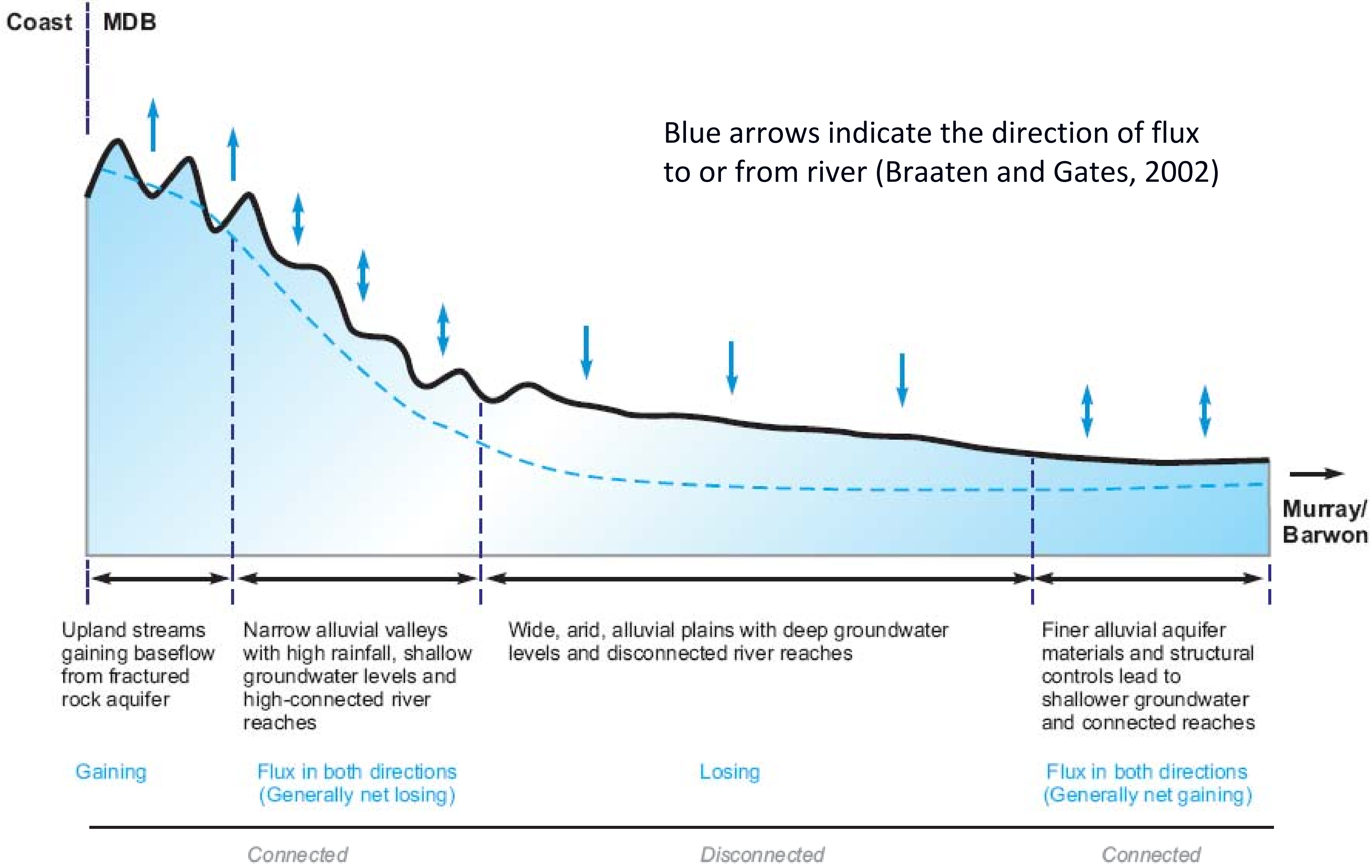
Stream-Aquifer Connectivity

(after REM, 2002)

Contiguity*	Seepage Direction	Synonyms	Potential impact of groundwater on surface water	Potential impact of surface water on groundwater
Contiguous	Gaining	Effluent Upwelling Groundwater-fed Aquifer discharge	High	Low
Contiguous	Losing	Influent Down-welling Stream-fed Aquifer recharge	Medium	High
Contiguous	Underflow		Low	Medium
Perched	Losing	Disconnected	Very Low (not none)	Medium
Contiguous	Fluctuating	Variable Gaining/Losing Seasonal	Medium	Medium
Contiguous	Throughflow	Flowthrough	Medium	Medium

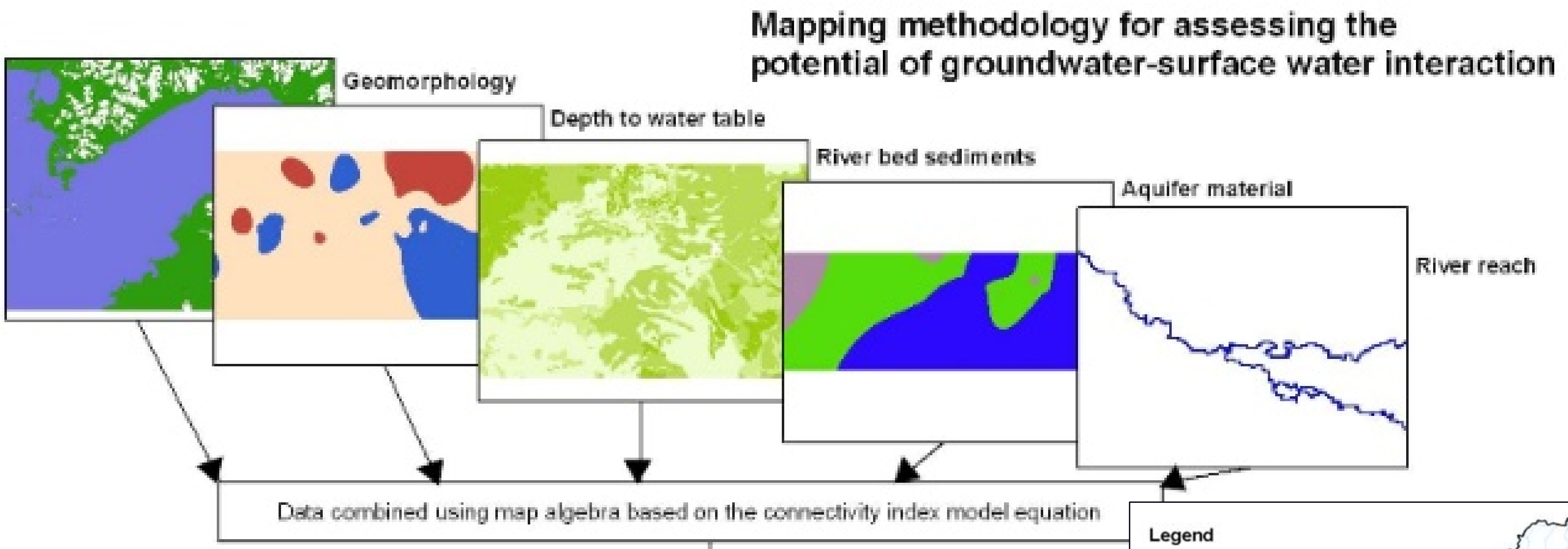
*contiguous is synonym for saturated

Connectivity Mapping



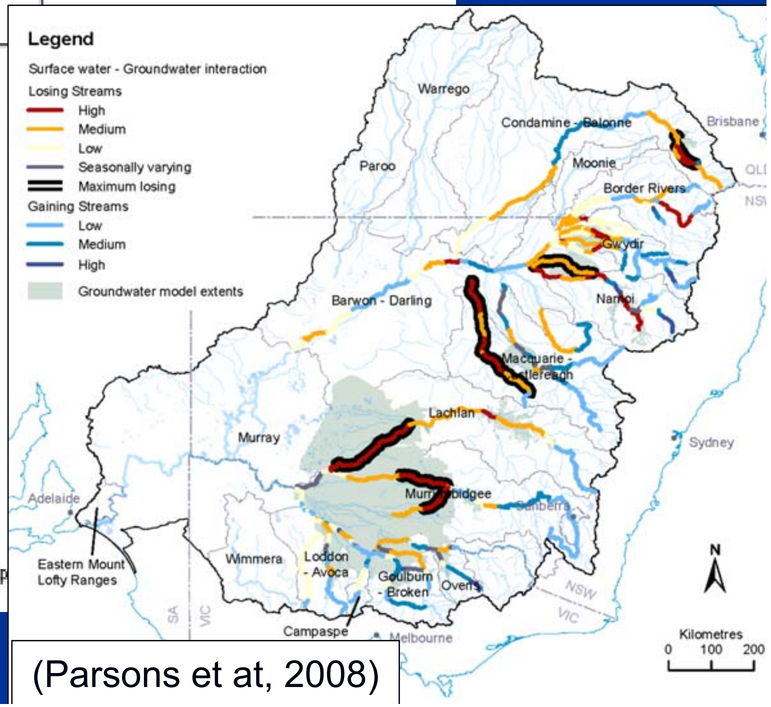
Blue arrows indicate the direction of flux to or from river (Braaten and Gates, 2002)

Connectivity Mapping



Critical data: stream bed level.

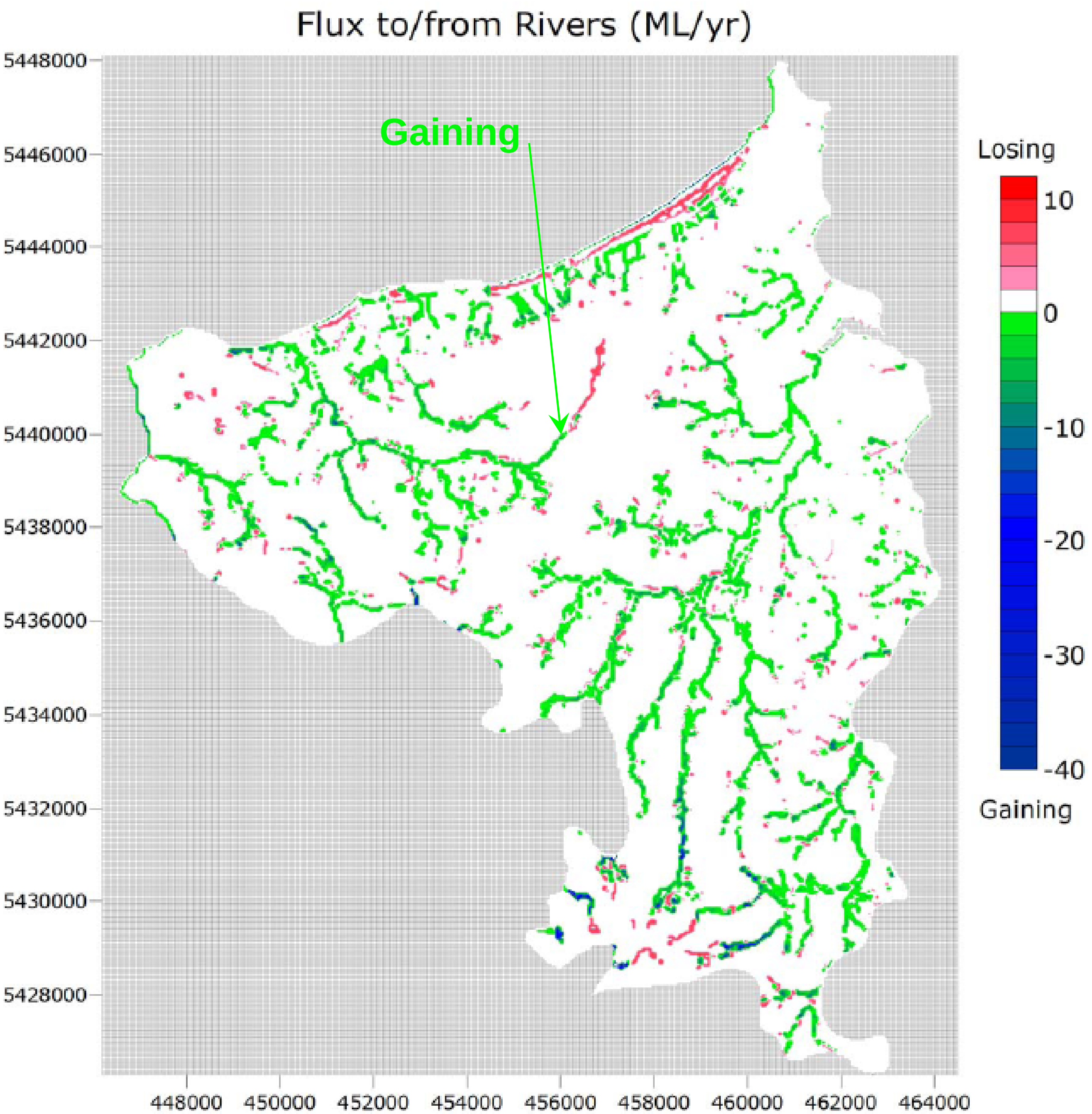
Where is it?



(Parsons et at, 2008)

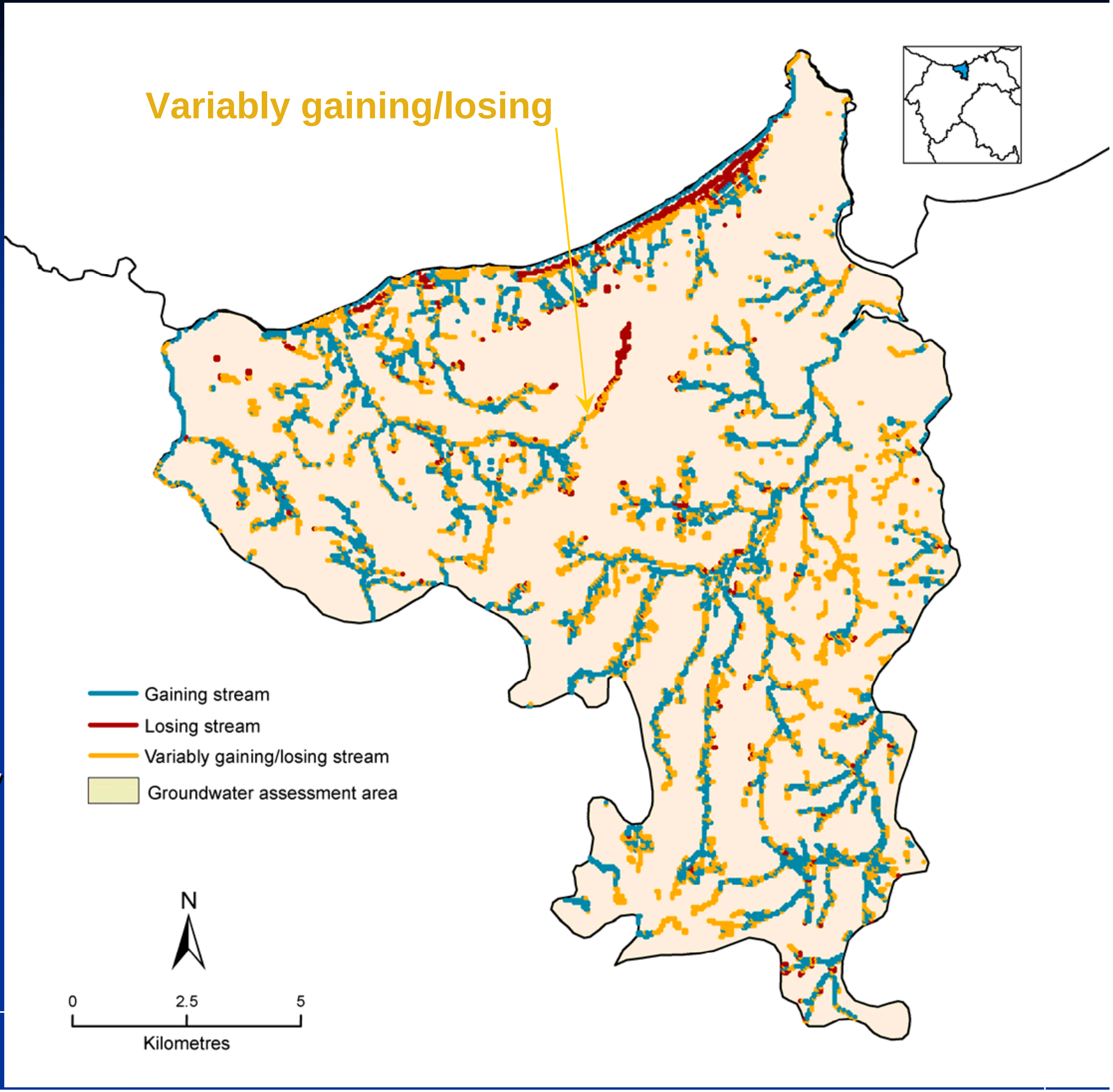
Tassie SY Project

Steady State (long term average)



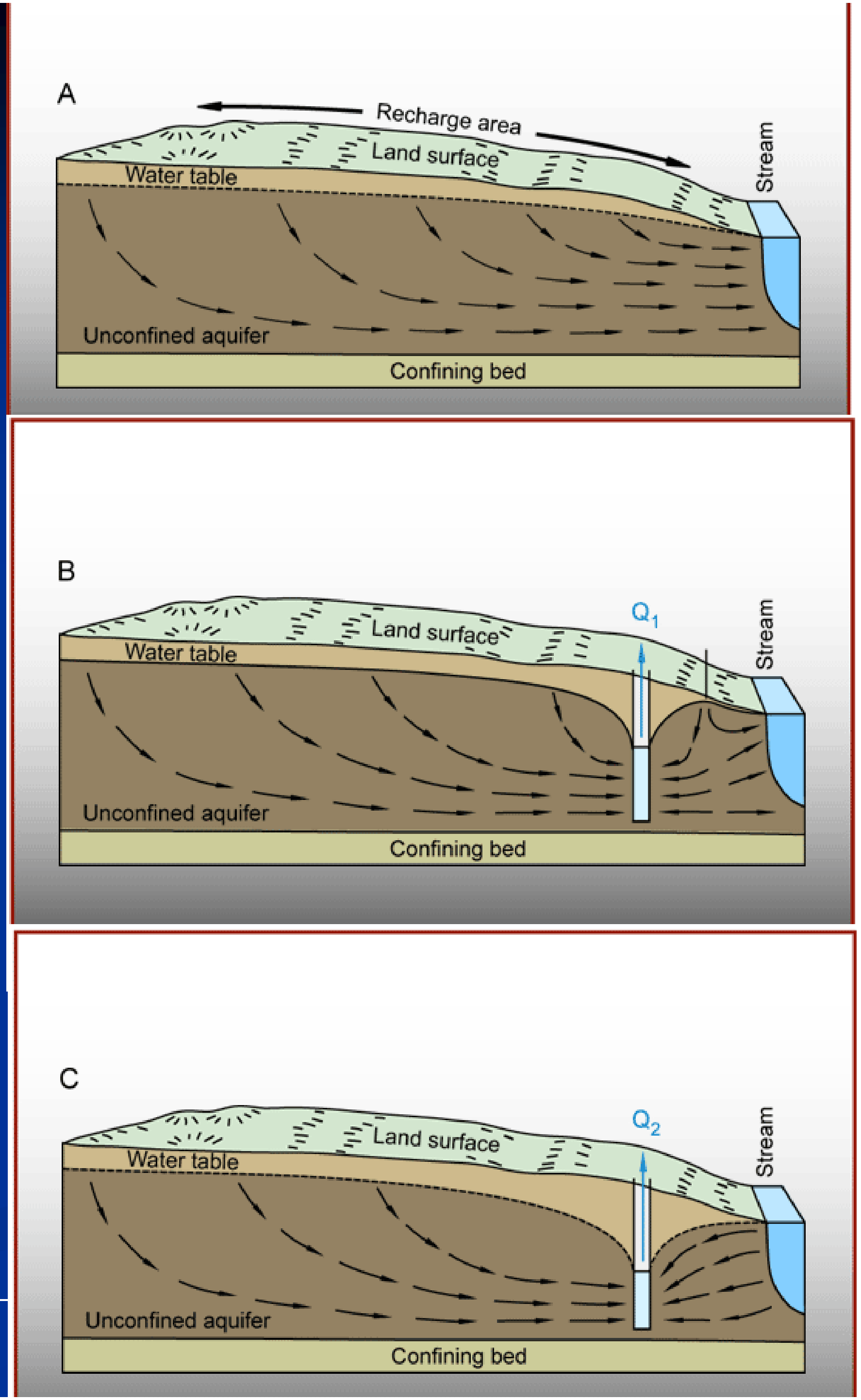
Tassie SY Project

Dynamic Connectivity

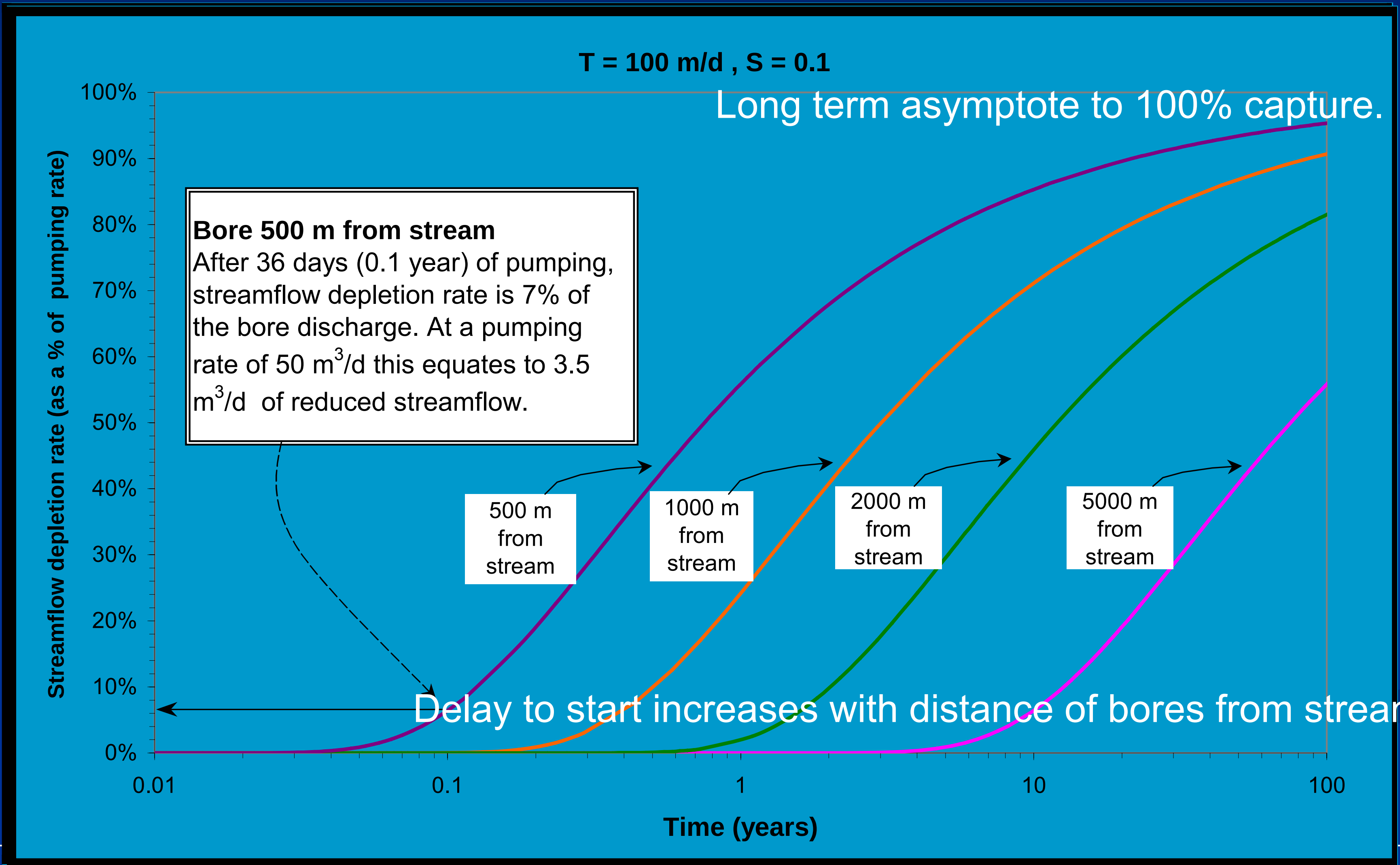


Induced Leakage by Pumping

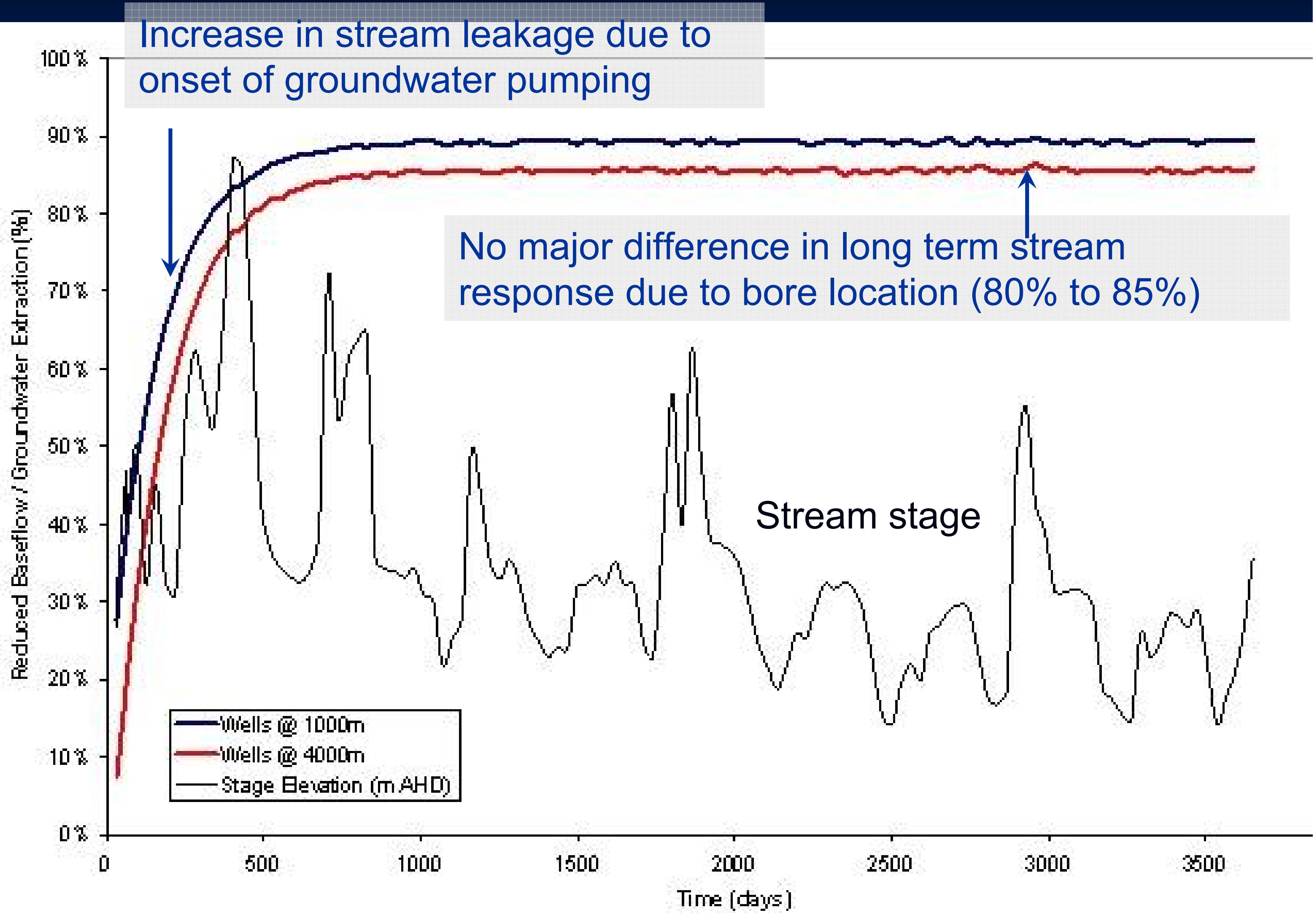
- A: Natural Groundwater baseflow to stream (gaining stream)
- B: Pumping induces leakage (variable)
- C: Long term pumping can reverse gradients (induced leakage from losing stream reaches)



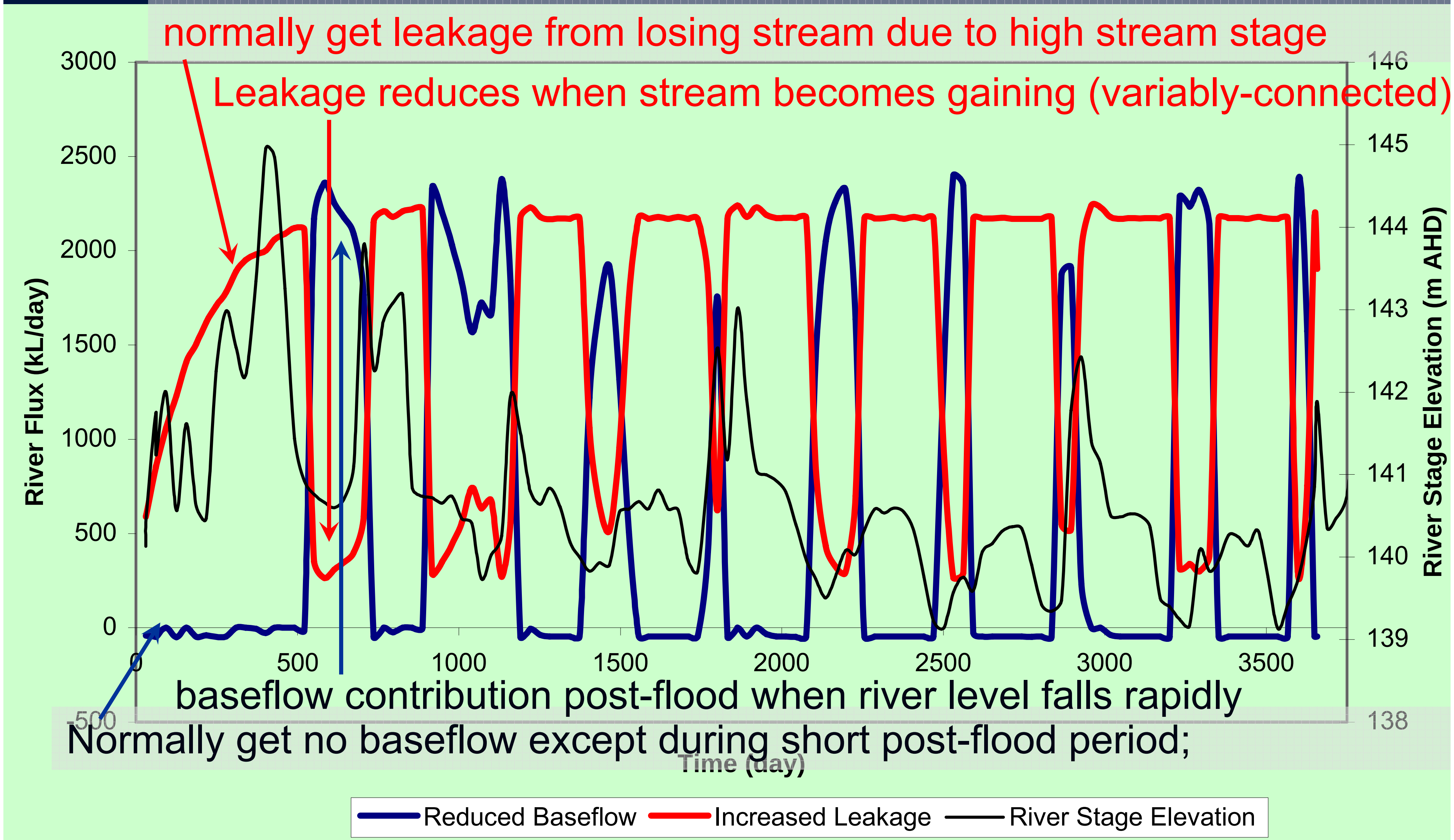
Proportion of Stream Depletion due to GW Pumping (analytical fn)



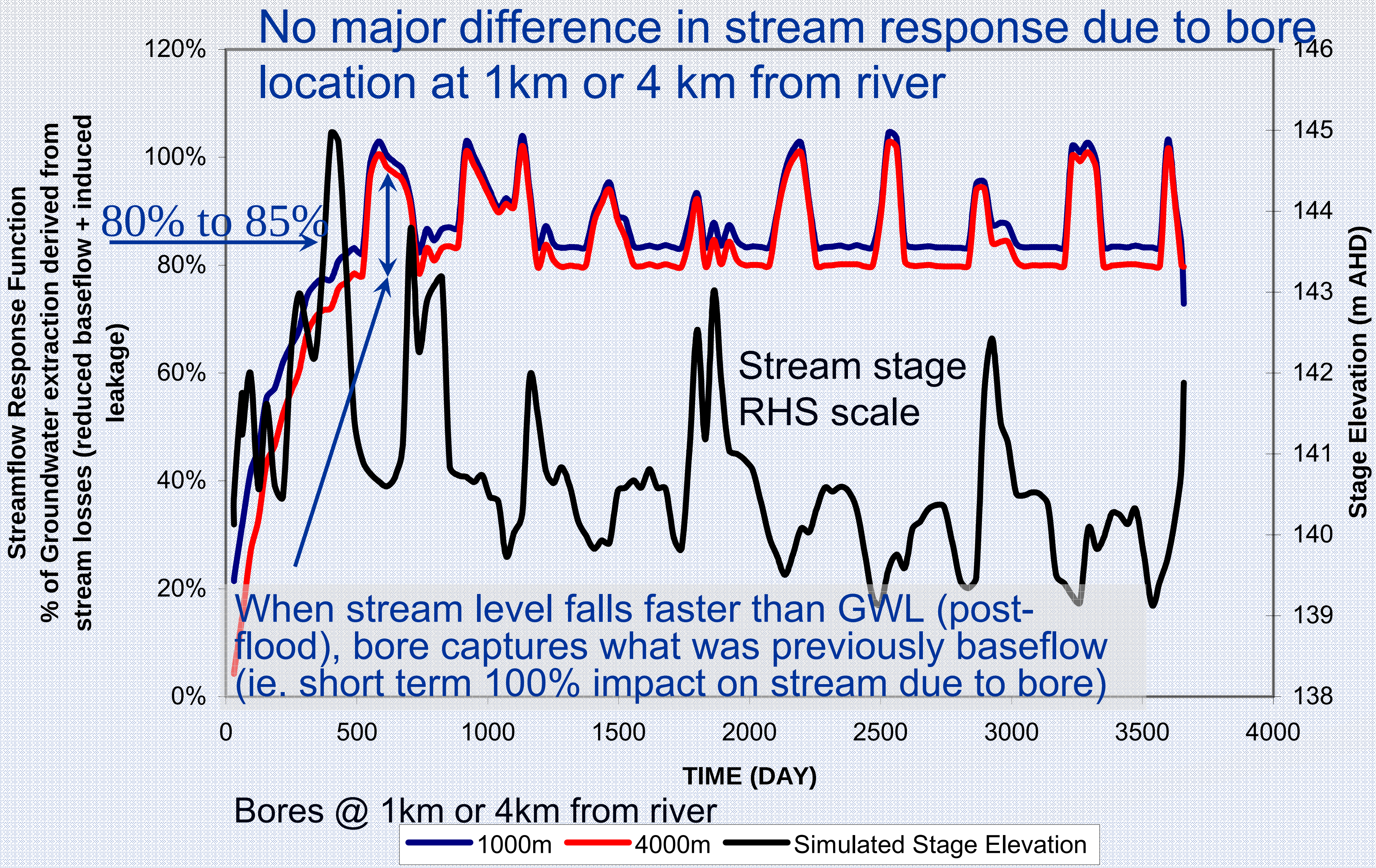
Connected-Gaining Stream



Variably Connected (losing / gaining) Stream



Variably Connected (losing / gaining) Stream



Bores @ 1km or 4km from river

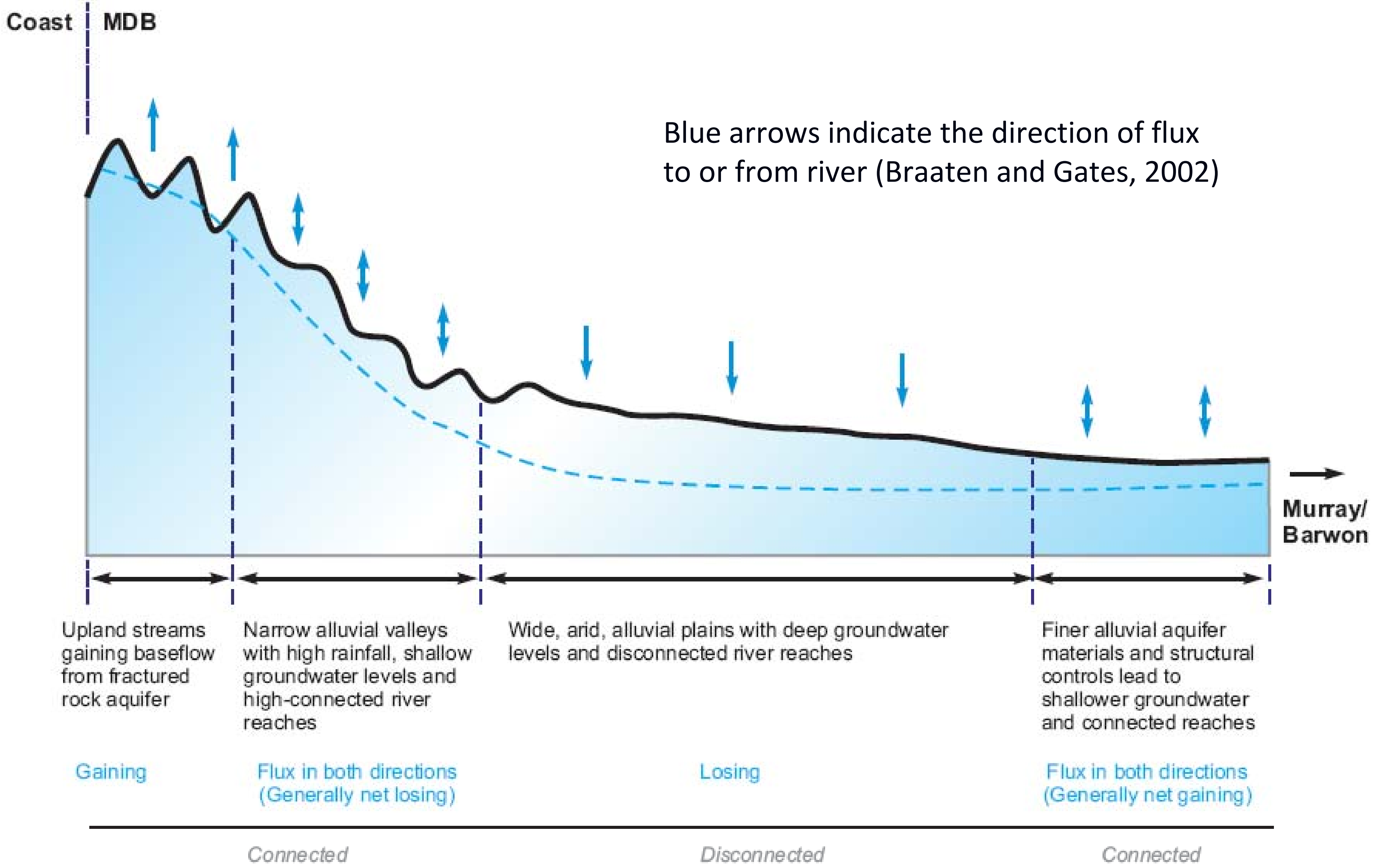
Conjunctive Mgt Model

- connected systems are predictably affected by reduced baseflow due to lower GWLs (eg. due to drought/pumping)
- variably-connected streams are at risk from pumping impacts during/following flood periods when levels are high
  - because groundwater abstraction can “capture” short periods of what was natural baseflow during flood recessions when the river level recedes faster than the GW level

Conjunctive Mgt Model

- **Site-specifics are crucial**; they determine the nature, extent and magnitude of stream-aquifer interaction processes
- **Magnitude and direction** of flow contributions are affected by interaction process timings, and thus the conjunctive management practices/timings applied
- Generic management approaches should not be applied to important/priority catchments without also undertaking field investigations and modelling studies using site-specific data

Connectivity Mapping



Integration Issues

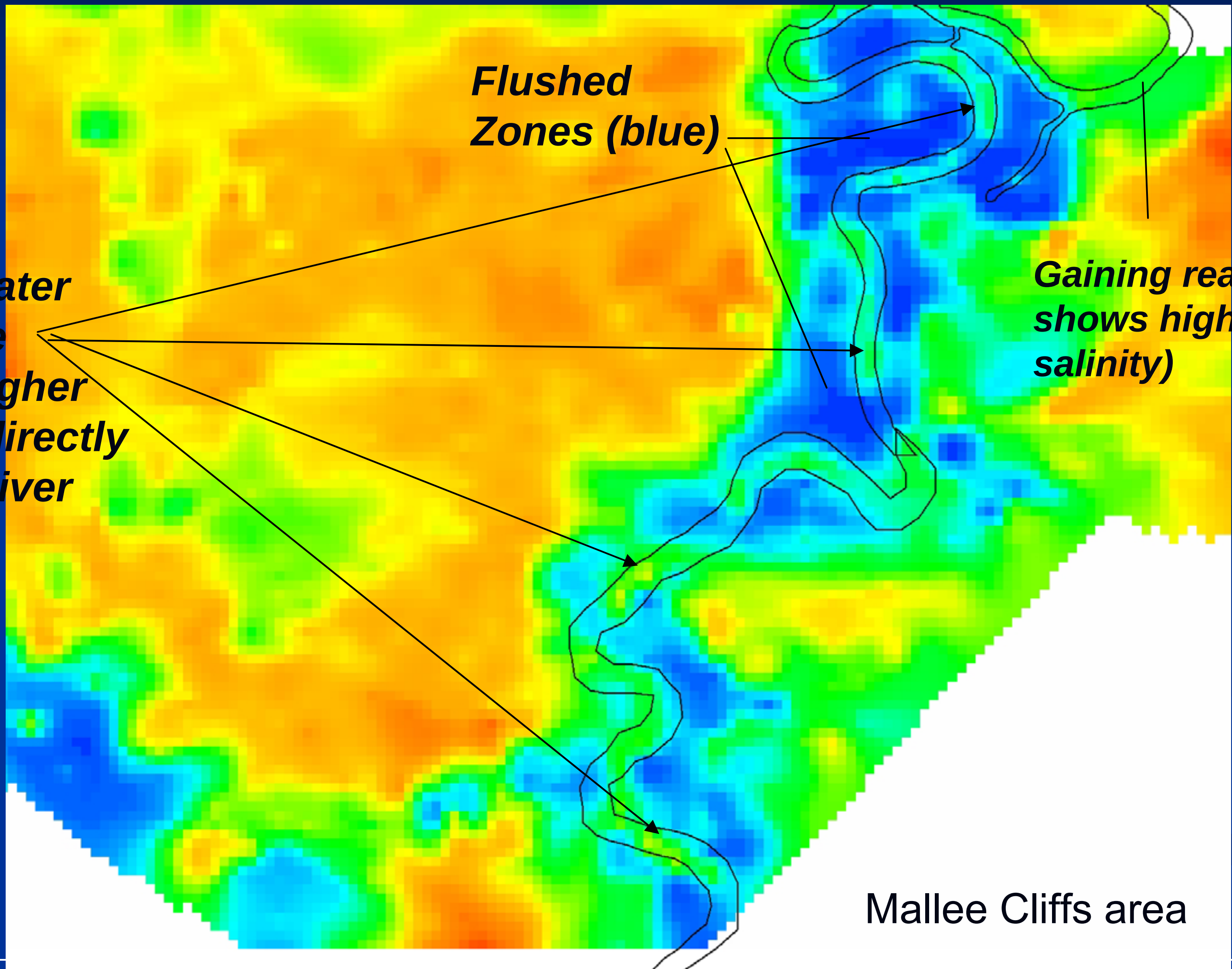
- Basin Plan: 35 separate SW & GW models
- SW models IQQM & REALM are hydrological triumphs but hydraulic/process deserts, with unaccounted loss/gain relationships for GW
- GW models better, but too simple re SW?
- SW-GW linkages invoked too simply?
- Closing water balance difficult/uncertain?
- May be fit for purpose….
- But is this practice good enough?
- Integrated Models needed for key areas.

Floodplain Processes

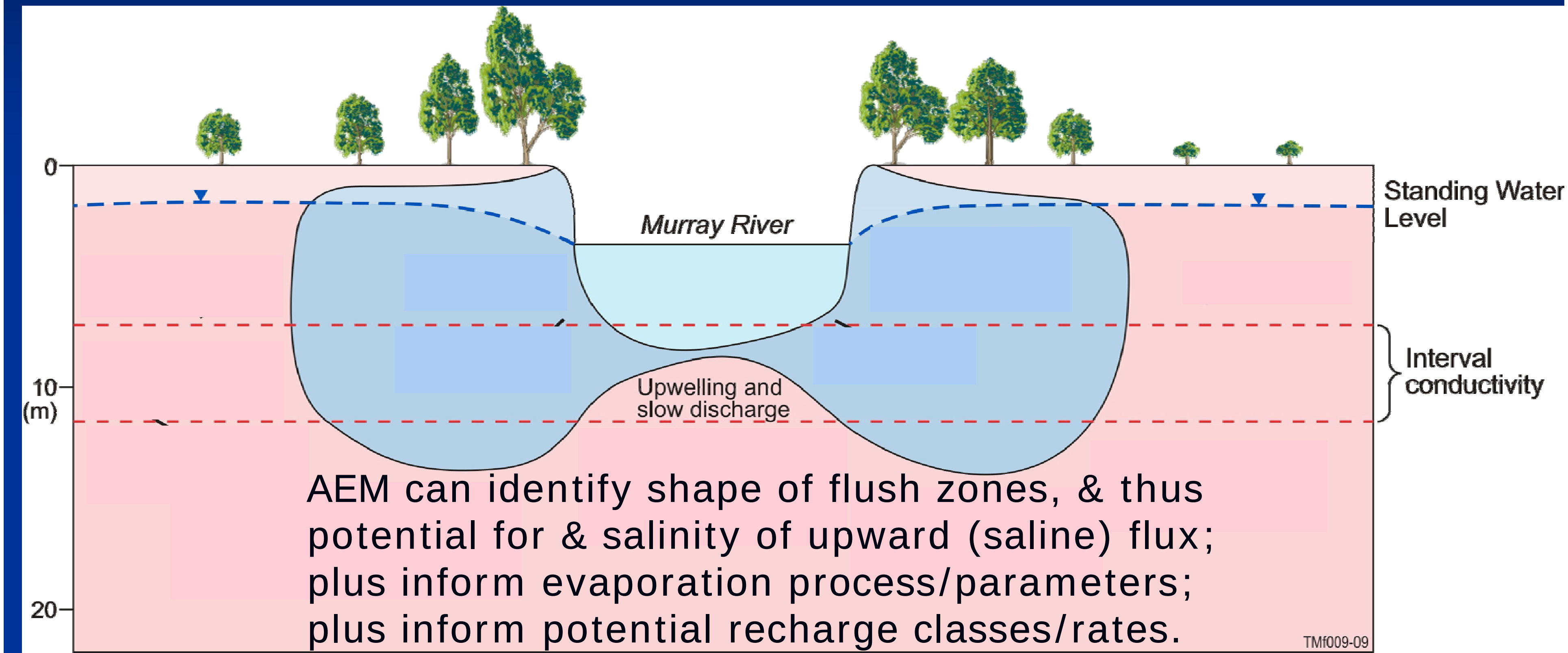
- EM4 groundwater flow model
- Salinity mgt context
- Simple Modflow stream features
- Complex recharge and evaporation
- River Murray floodplain, between Darling River and SA Border
- Murray River variably gaining/losing
- GW flow parallel to Murray River
- Mostly losing anabranches on F/P

Airborne EM

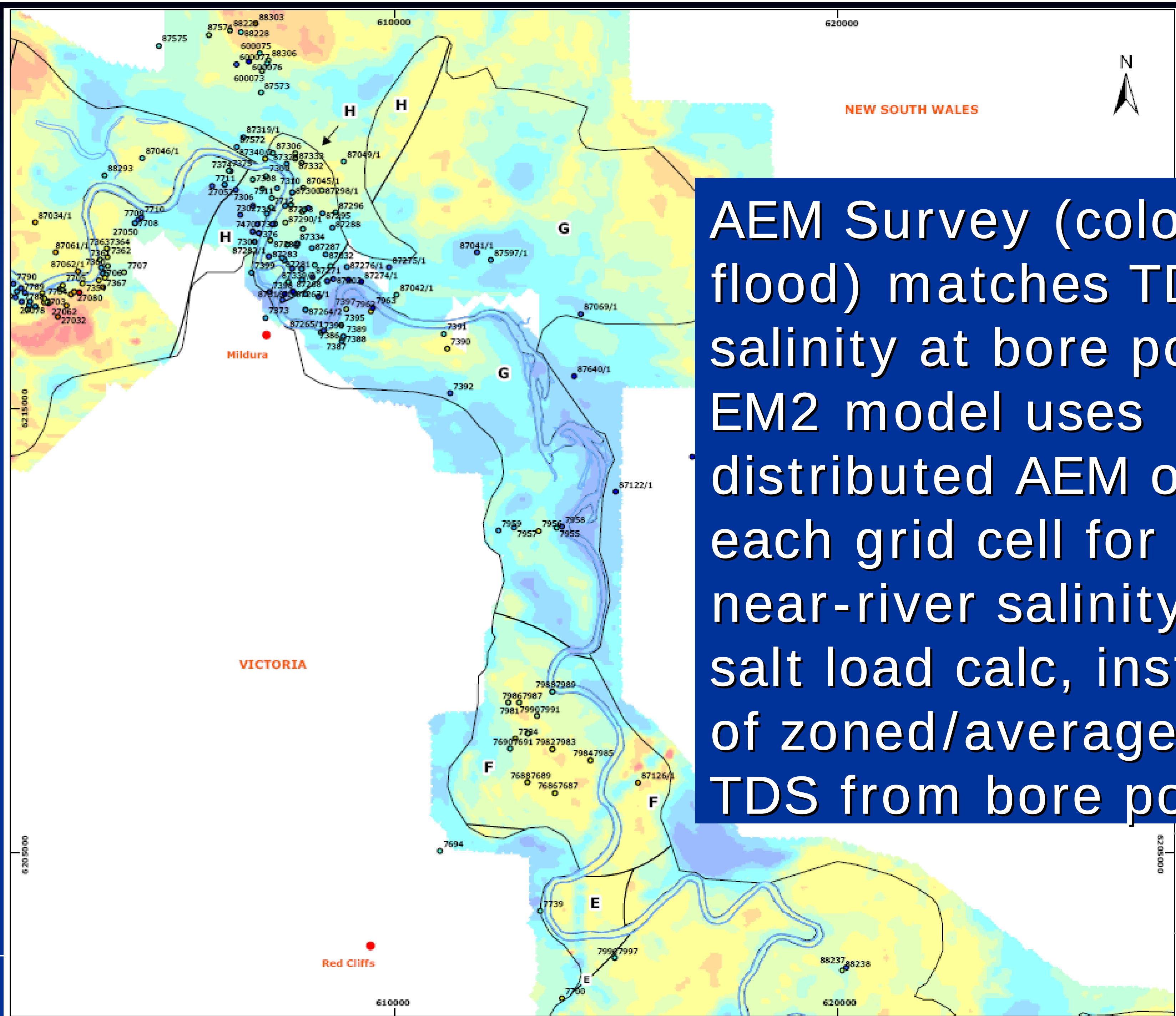
- continuous salinity distribution
- vertical flux to river



Airborne EM providing info on floodplain processes

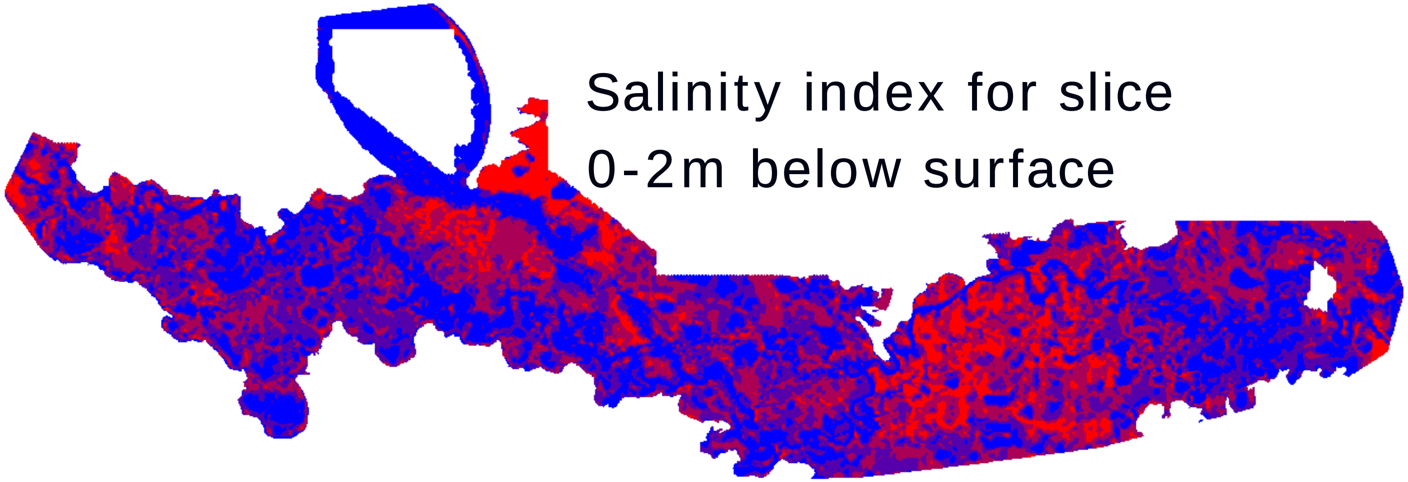


AEM can identify shape of flush zones, & thus potential for & salinity of upward (saline) flux; plus inform evaporation process/parameters; plus inform potential recharge classes/rates.



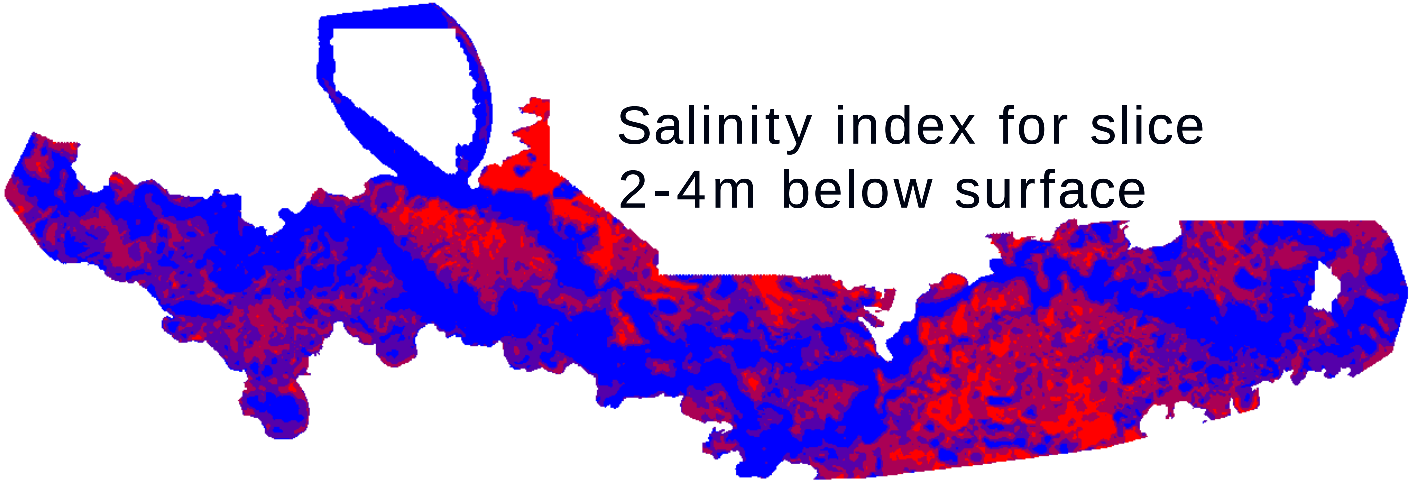
AEM Survey (colour flood) matches TDS salinity at bore points. EM2 model uses distributed AEM on each grid cell for near-river salinity for salt load calc, instead of zoned/averaged TDS from bore points.

AEM Potential recharge classes



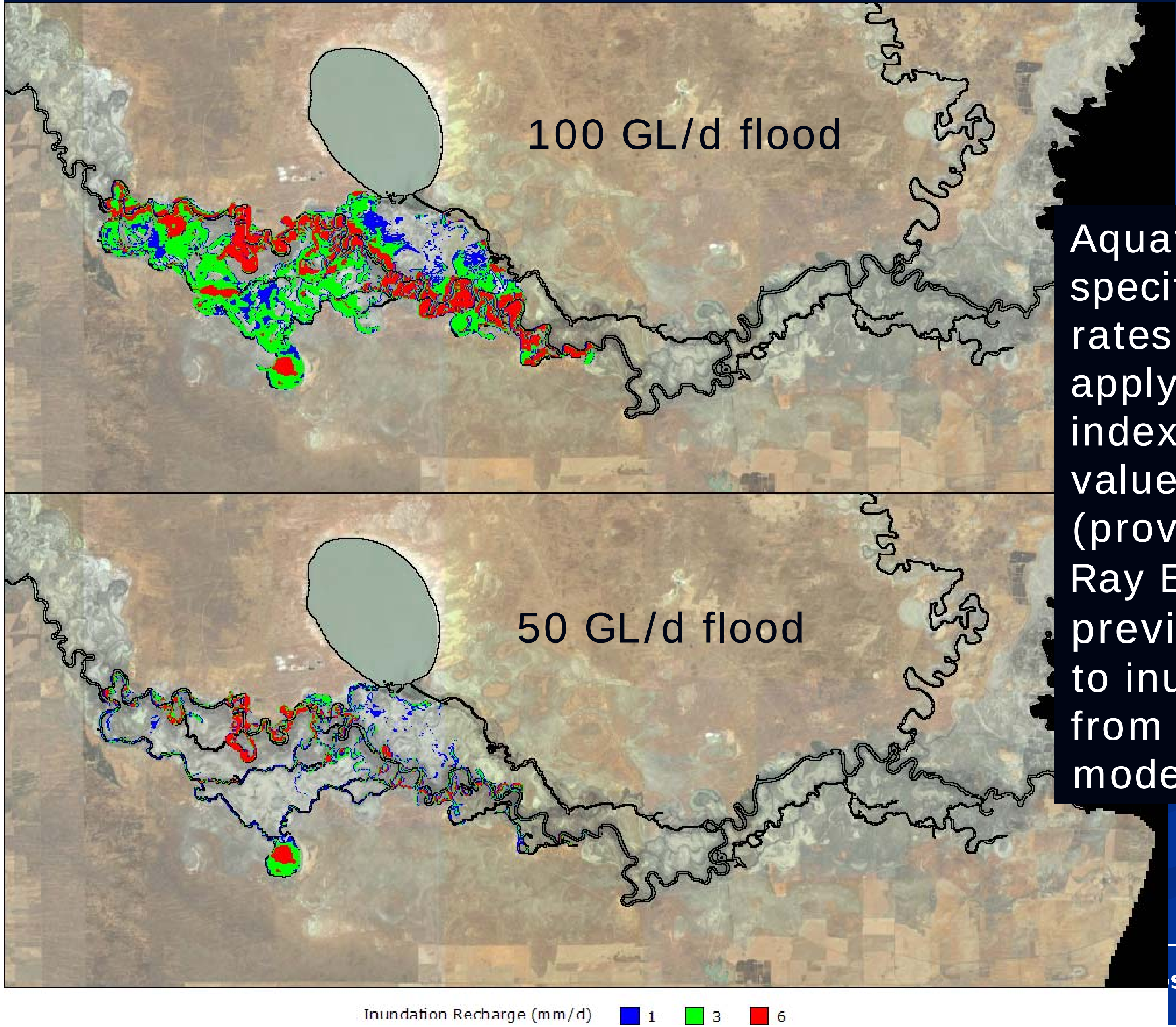
Salinity index for slice
0-2m below surface

Salinity index in 4 classes for AEM profile each slice.
Class 4 (red) = high salinity = low RCH potential
Class 1 (blue) = low salinity = high RCH potential.



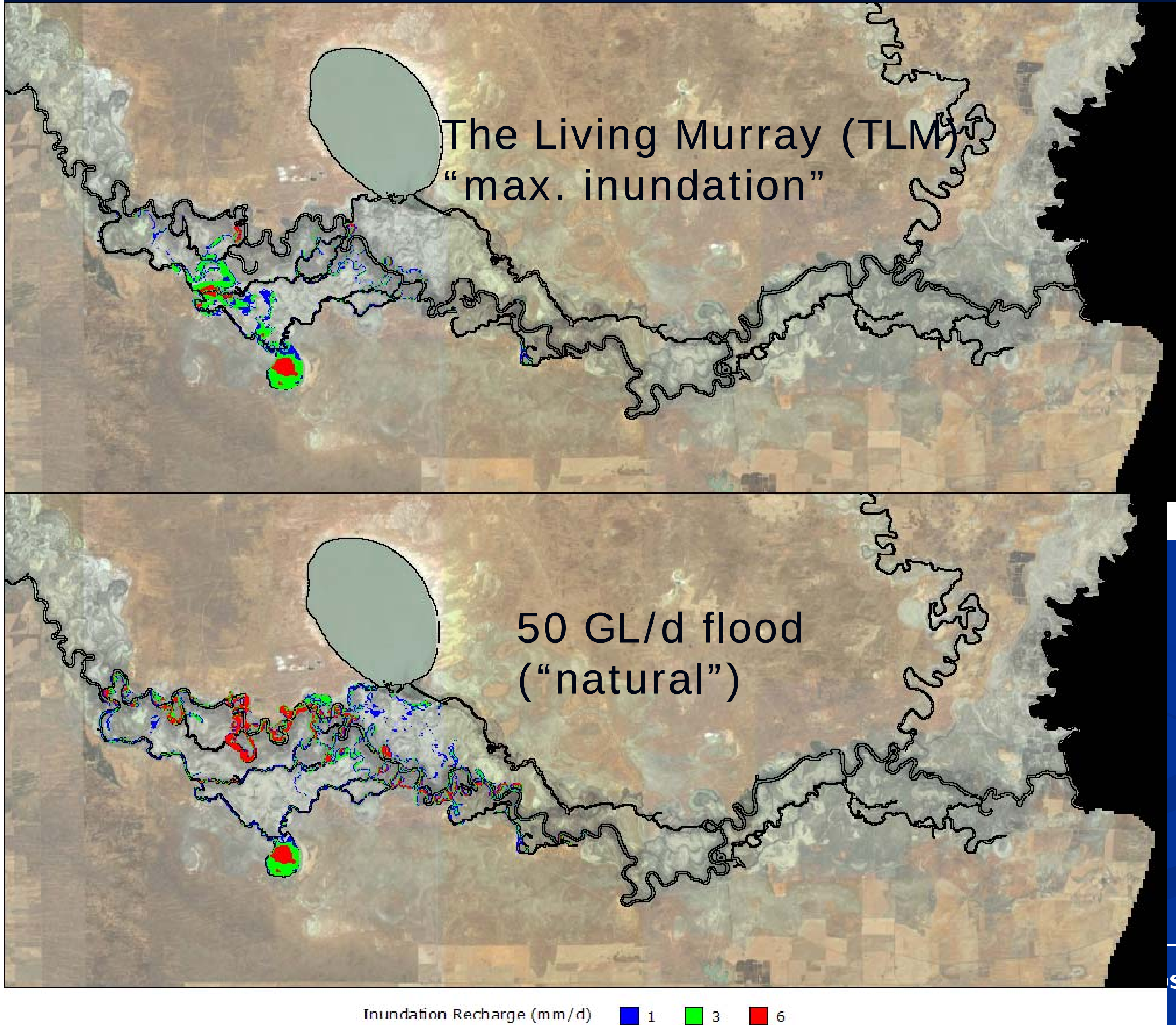
Salinity index for slice
2-4m below surface

Floodplain inundation recharge



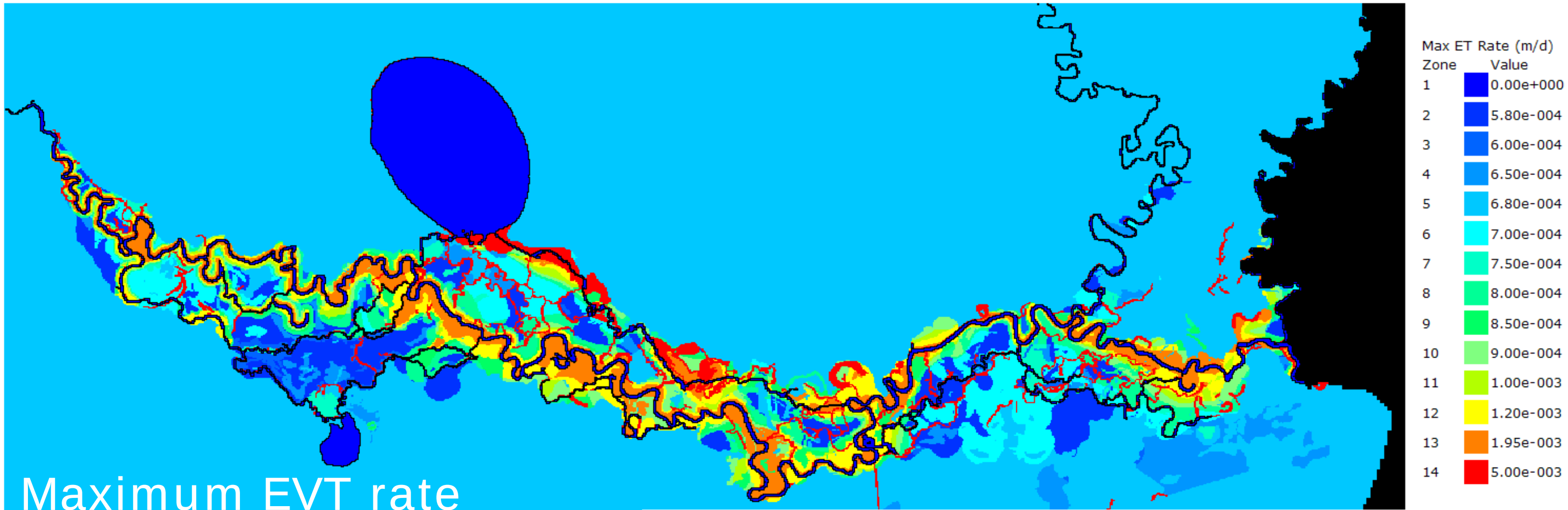
Aquaterra developed specific recharge rates (mm/day) to apply to AEM salinity index product values/classes (provided by SKM & Ray Evans, see previous slide), and to inundation extents from hydrodynamic model (WaterTech)

Floodplain inundation recharge



saquaterra.com.au

Floodplain evaporation model

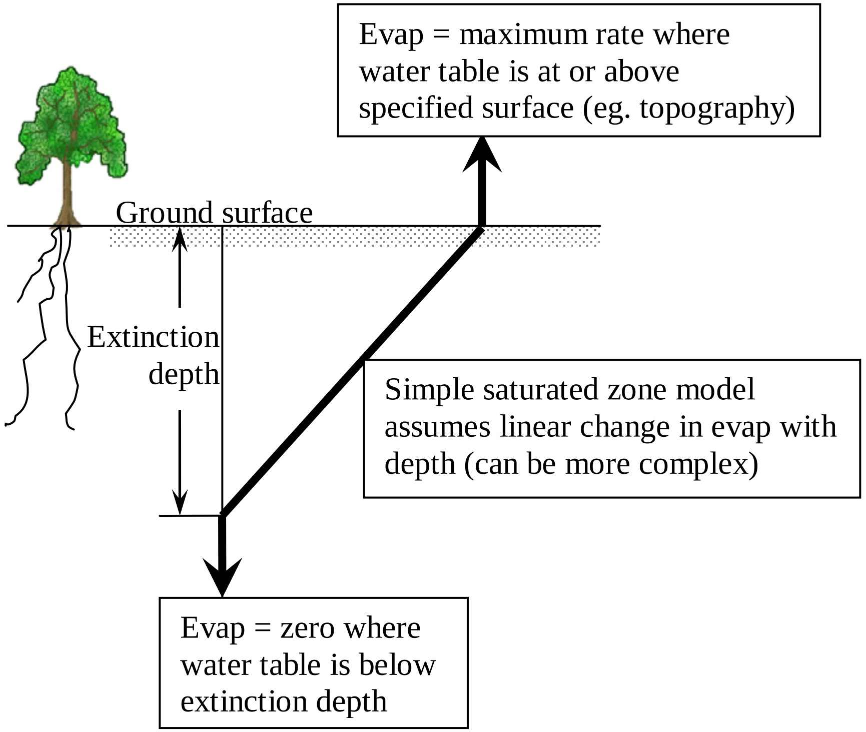


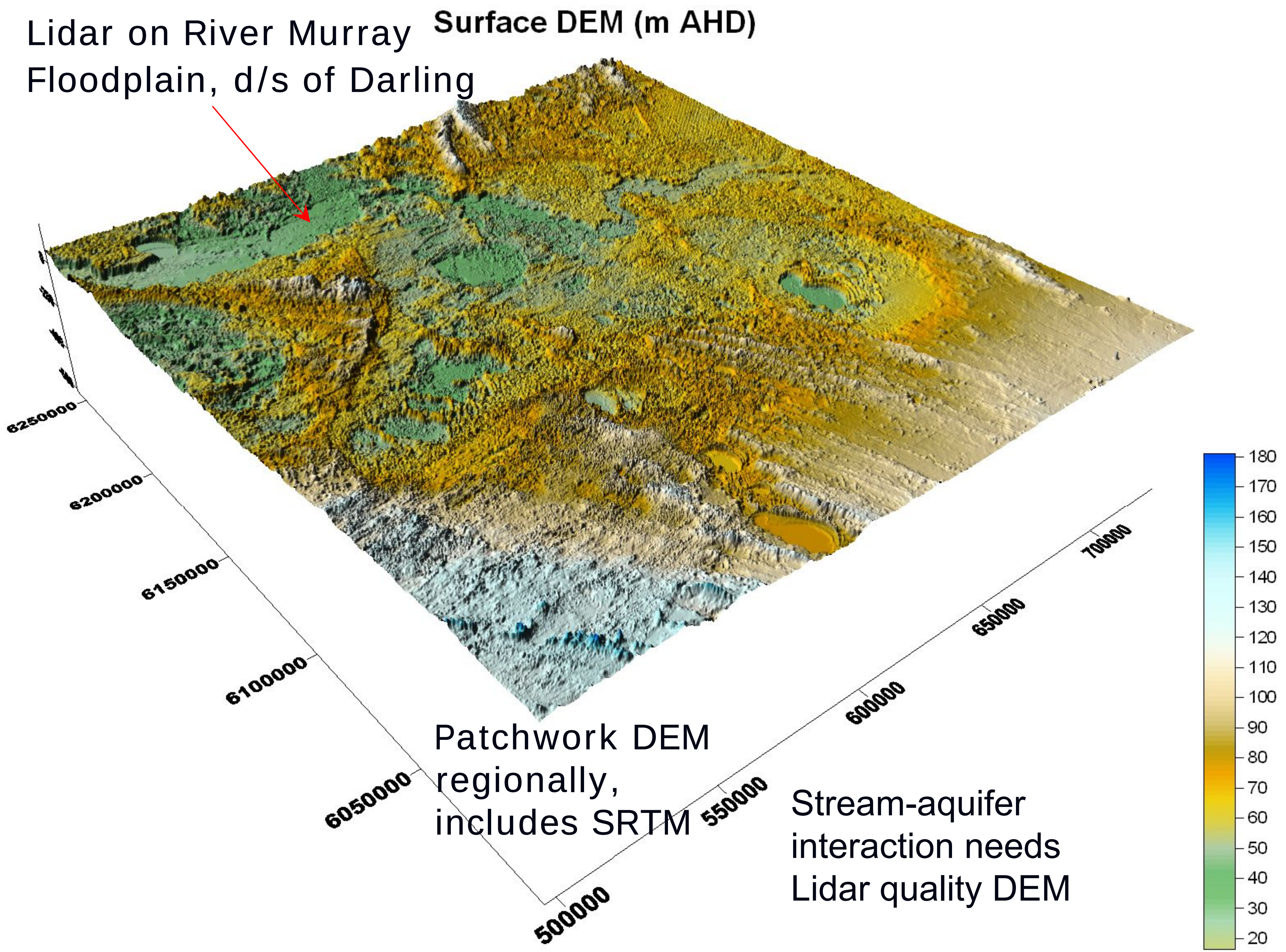
Maximum EVT rate

(from SKM; uses NDVI & T

AQT developed EVT spatial variability for extinction depth, and applied spatially variable max EVT rate.

More refinements required for long term recessions (>5 years).




Surface DEM (m AHD)
Lidar on River Murray
Floodplain, d/s of Darling
Patchwork DEM
regionally,
includes SRTM
Stream-aquifer
interaction needs
Lidar quality DEM
6250000
6200000
6150000
6100000
6050000
500000
550000
600000
650000
700000
180
170
160
150
140
130
120
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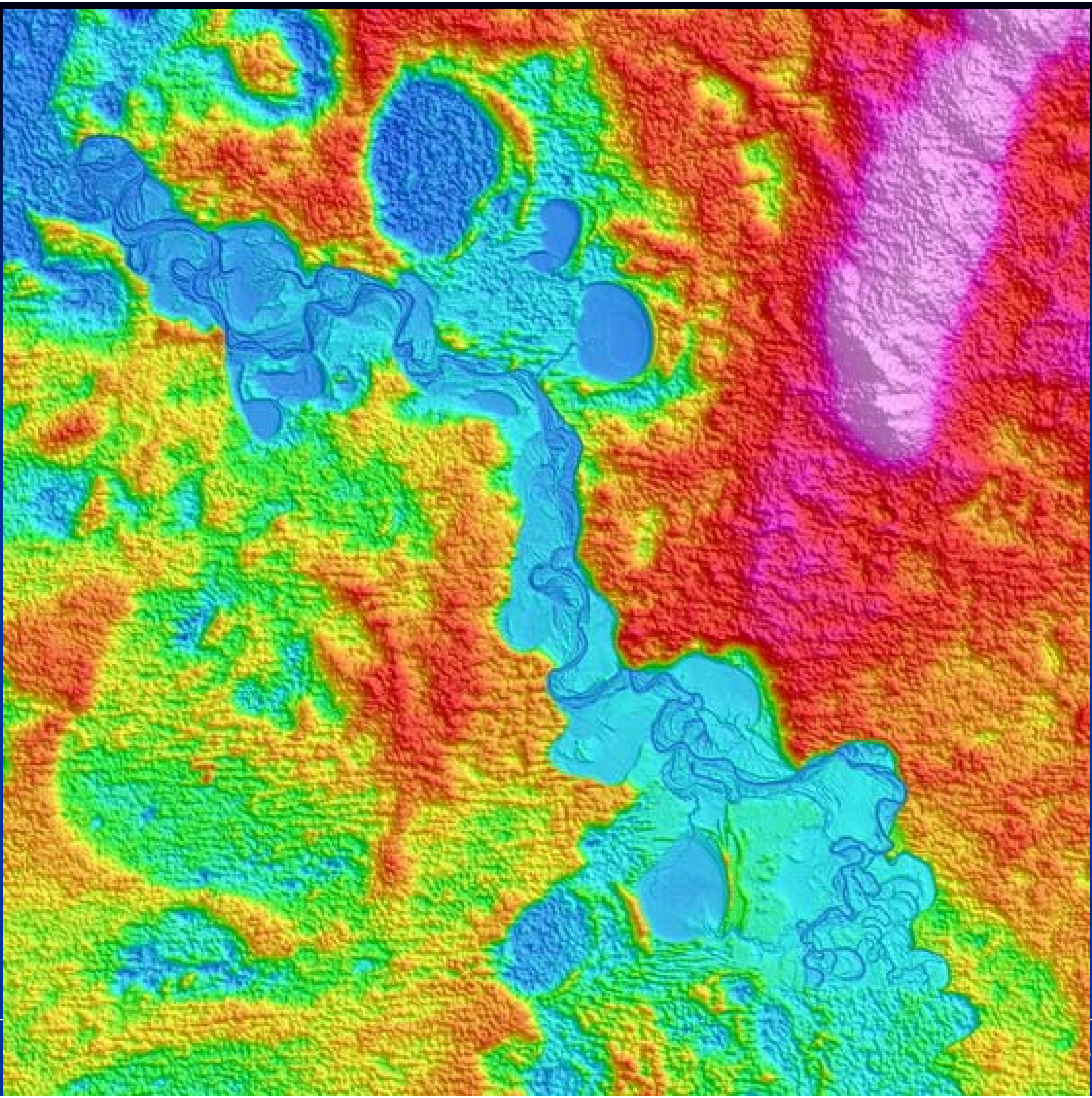
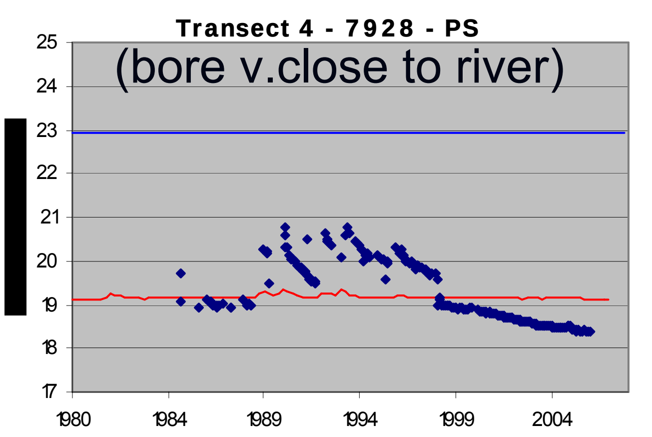
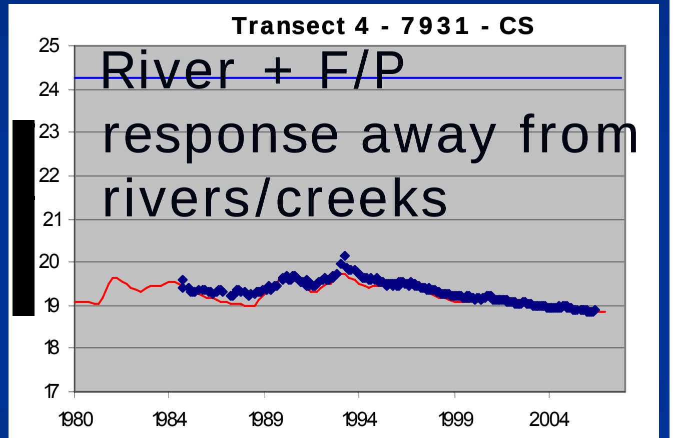
20

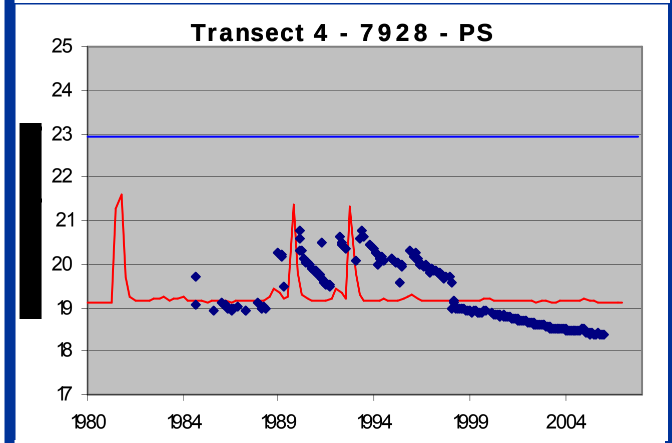


Model calibration to GW level response on floodplain

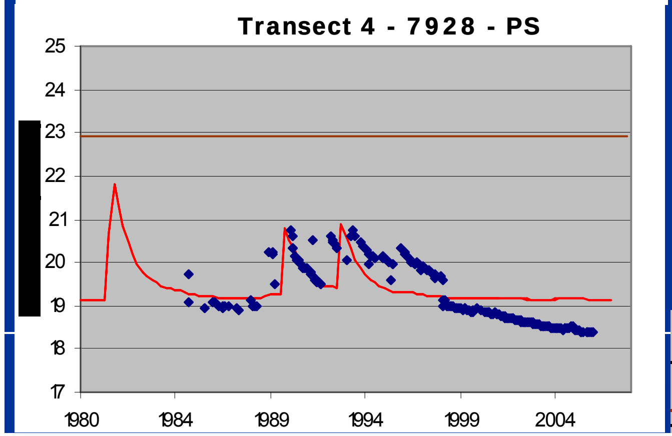


Initial model response to River only

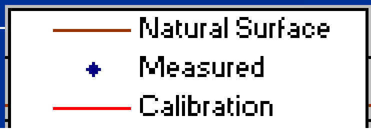


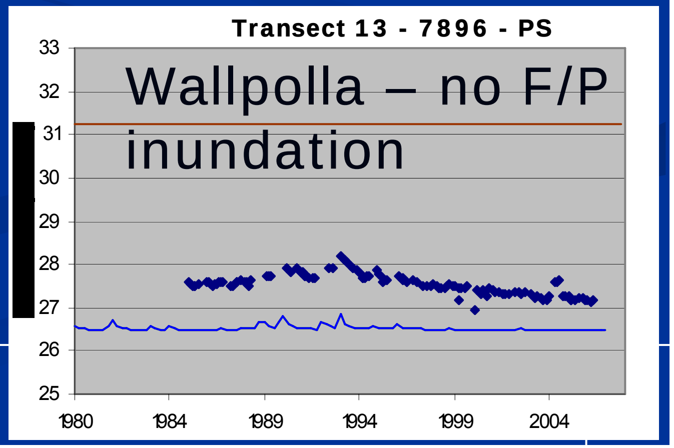


River features enhanced

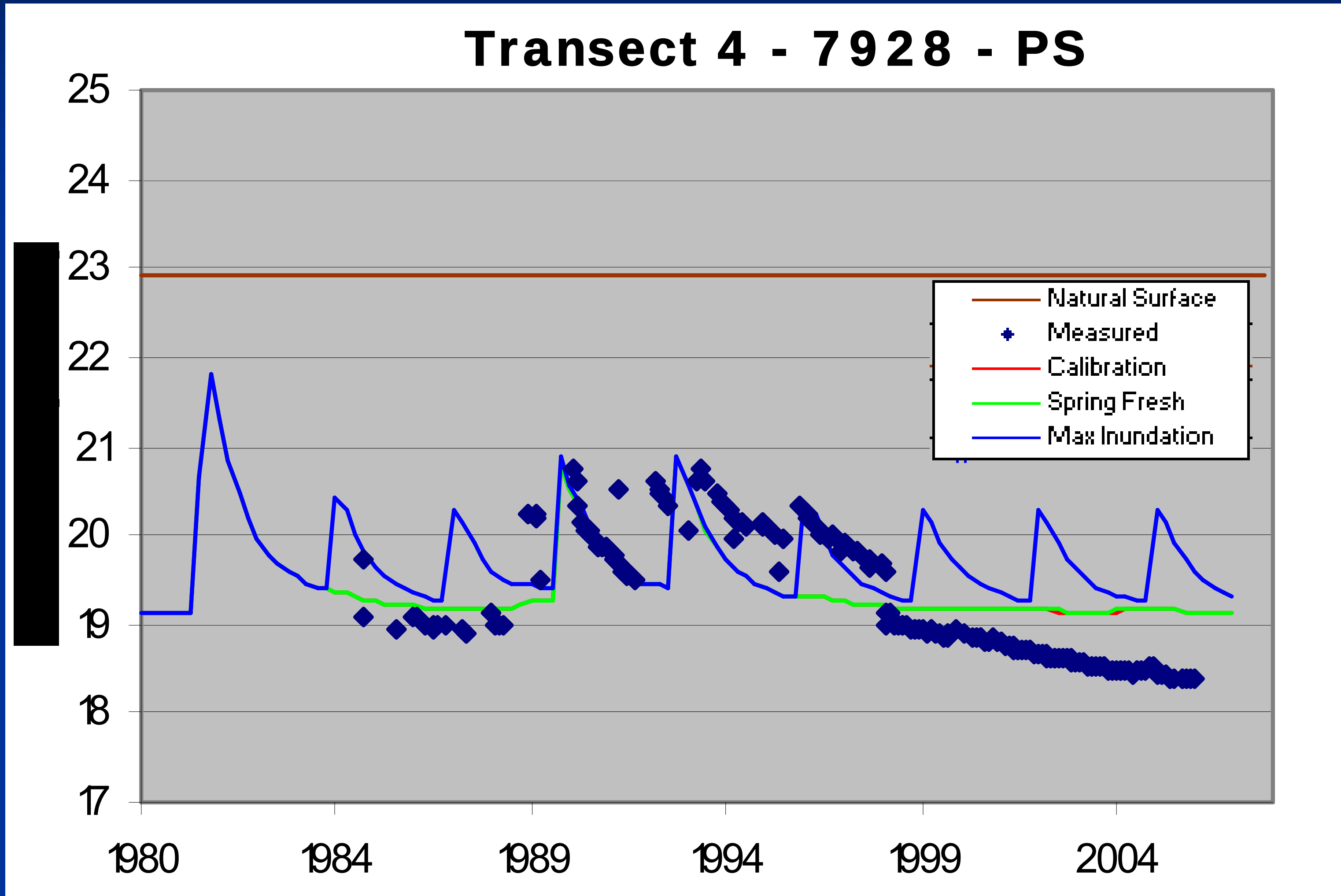


River + floodplain inundation + evaporation

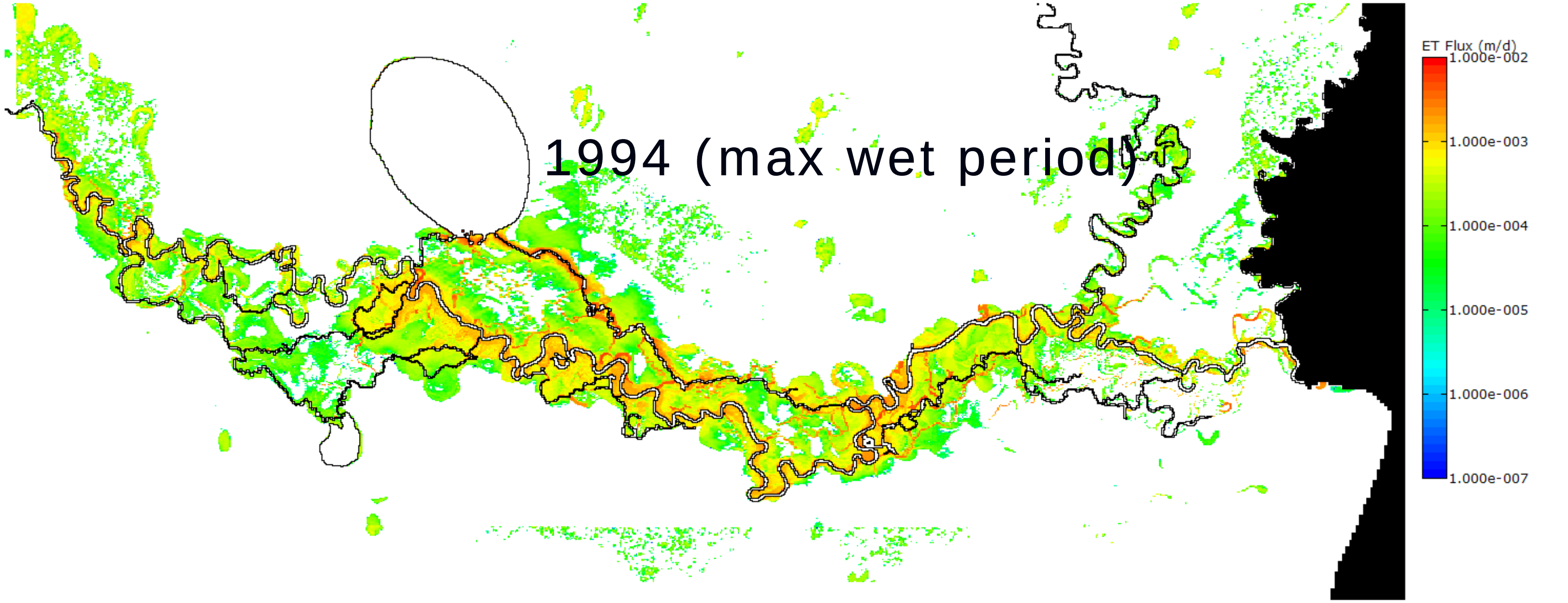


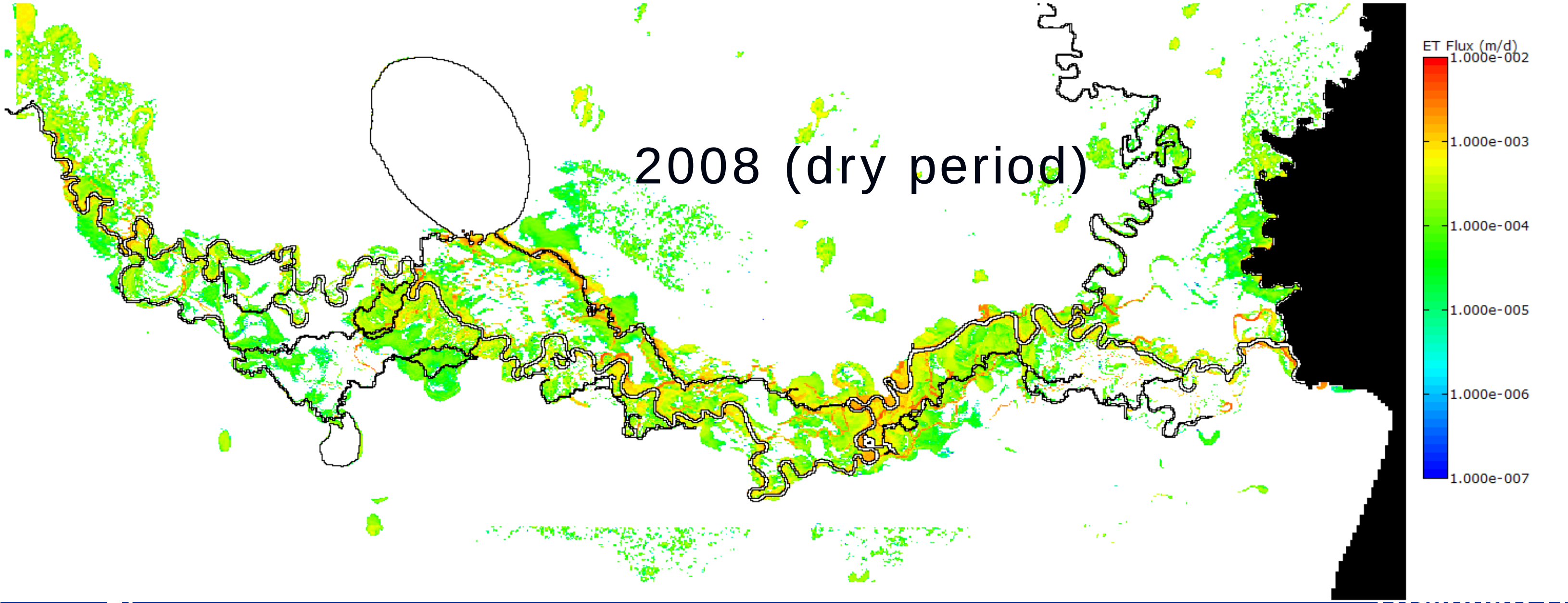


TLM prediction hindcast – long term recession needs better evap process

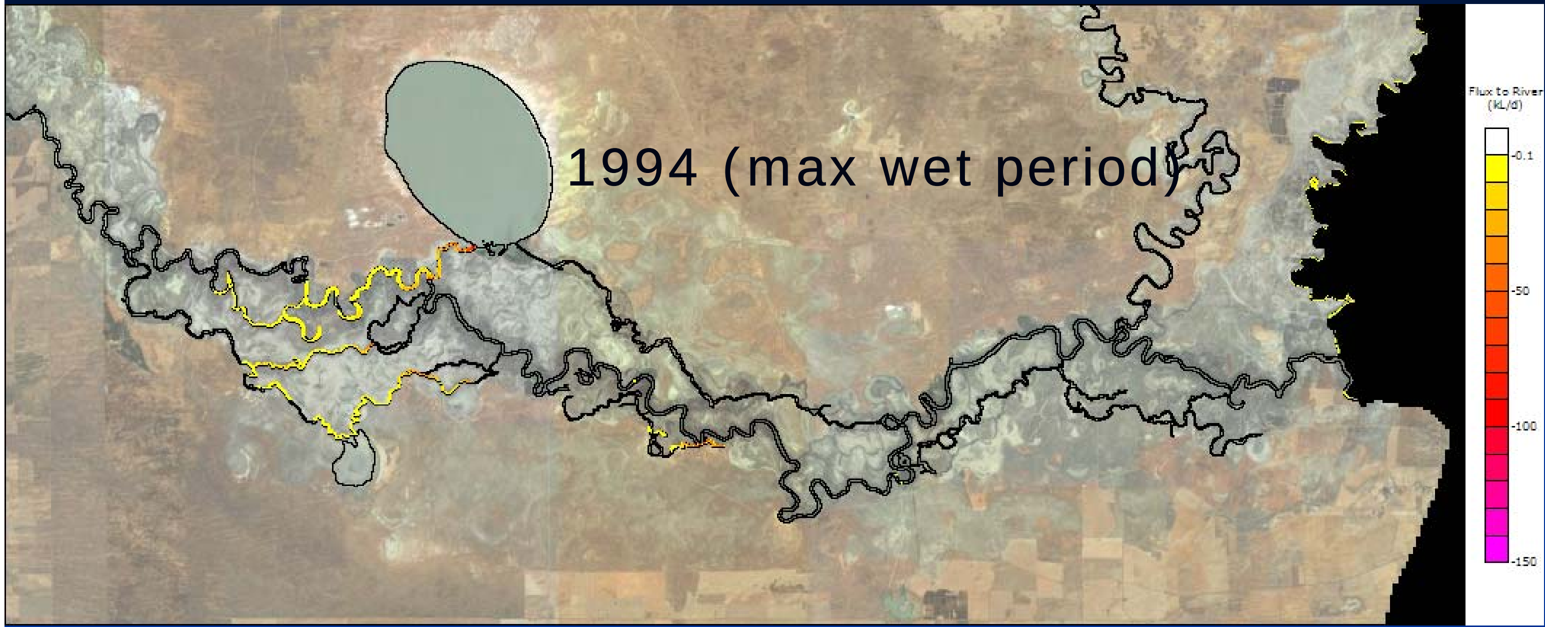


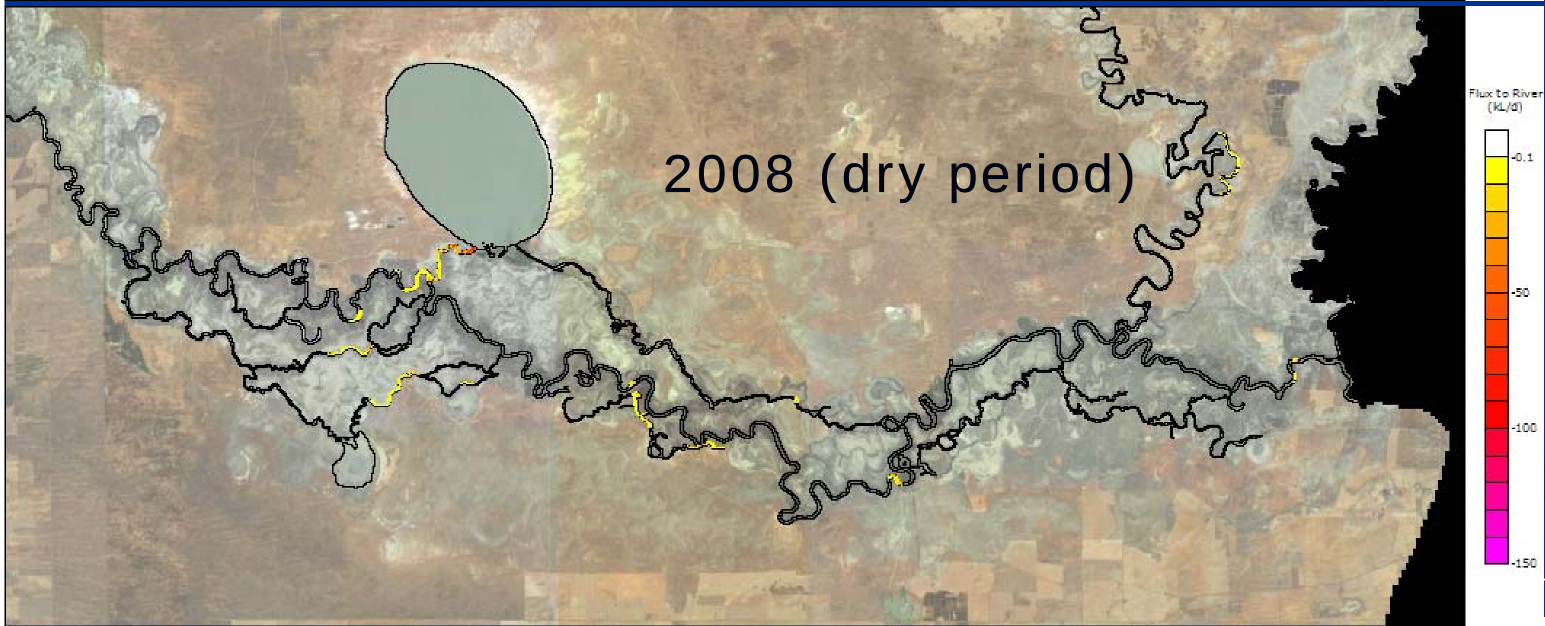
Evapotranspiration (model output)





Flux to streams (model output)





The Murray MIKE SHE project

South-west Western Australia

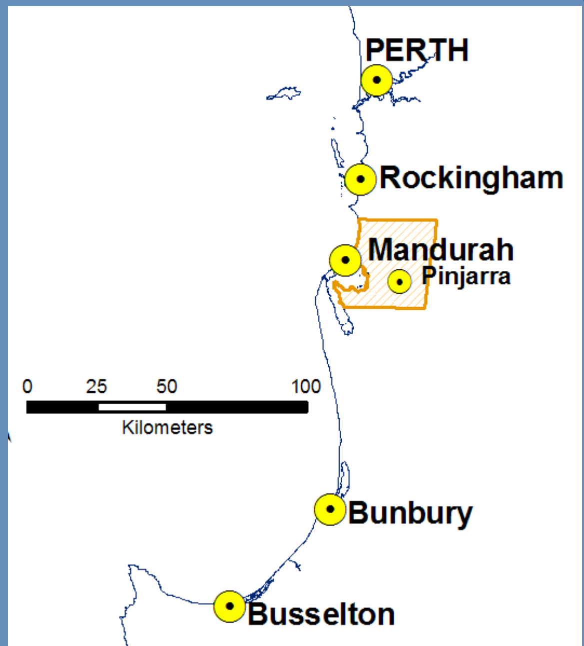
More than software...

Objectives:

- Determining the superficial groundwater levels and flows for a range of climate and development scenarios.

Issues:

- Water-logging, wetlands of significance, many drains that intersect and control groundwater levels, very high level of groundwater /surface water interactions.

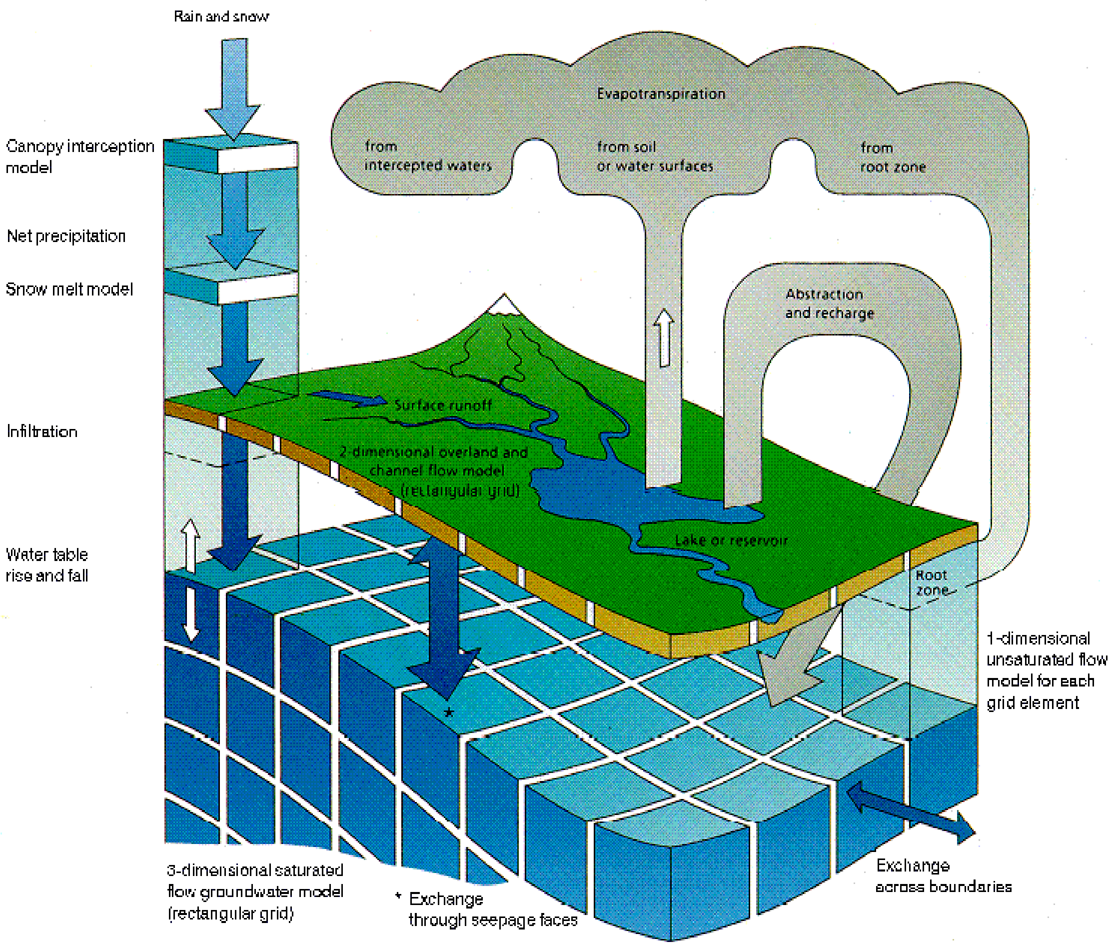


Murray (WA) MIKE SHE
Modules for Murray

More than software...

Five interacting modules in Murray MIKE SHE model:

- **Saturated zone**
  (200m fixed grid, 2 layers)
- **Unsaturated zone**
  (2-layer model)
- **Overland flow**
  (explicit numerical solution)
- **Evapotranspiration**
  (simplification of the Kristensen & Jensen model)
- **Rivers**
  (Mike 11 fully dynamic)



Run time* ~ 24 hours = 30 yrs

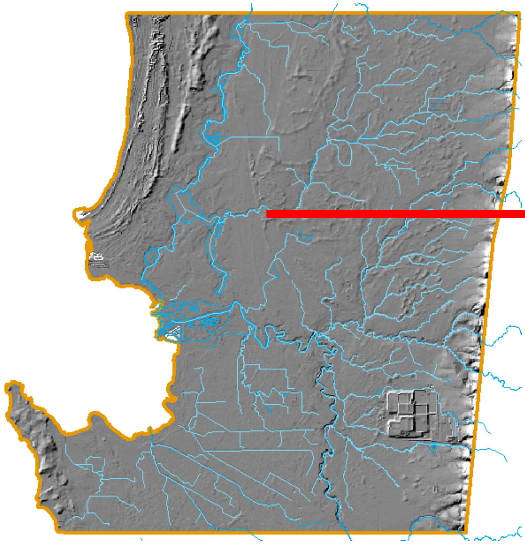
* 32 bit quad core @2.83GHz with 4GB RAM

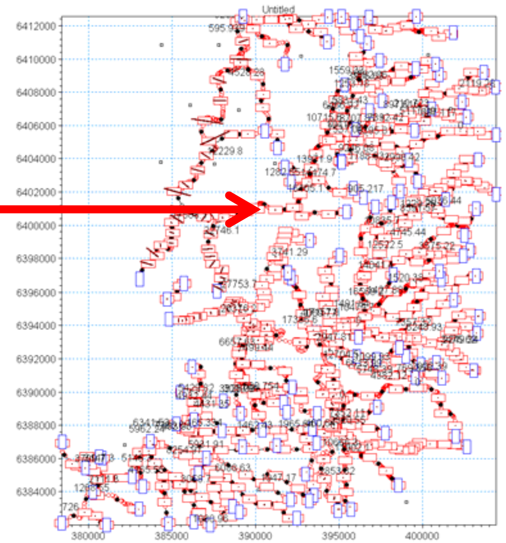
Murray (WA) MIKE SHE

Model construction

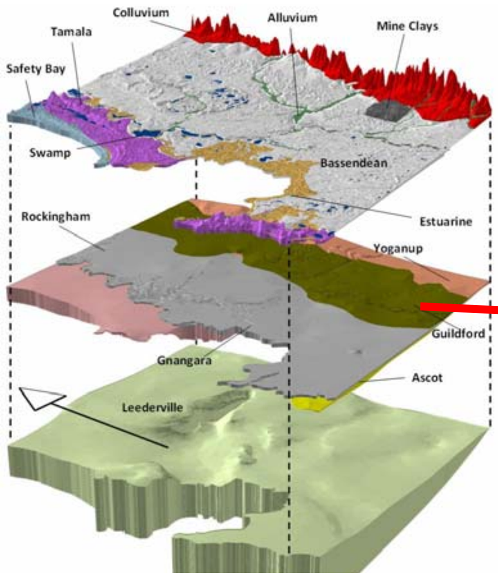
More than software...

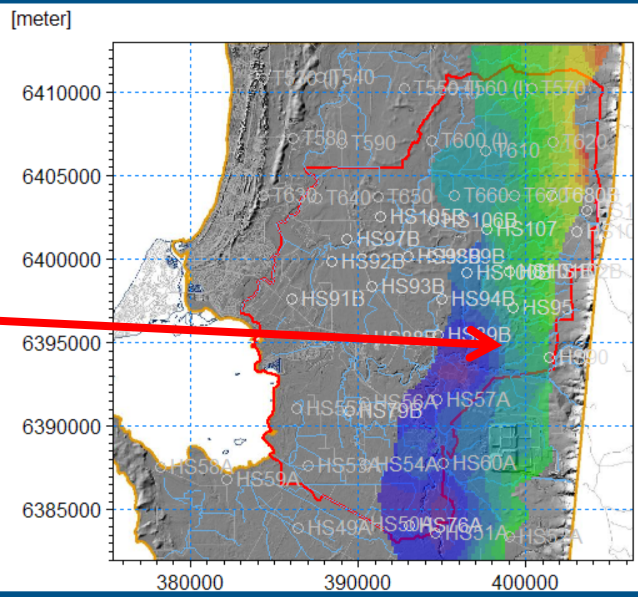
River network constructed using LiDAR for channel cross sections and MIKE 11 GIS extension





Geological model constructed using scripts to transform GIS rasters directly to MIKE SHE .dfs2 files



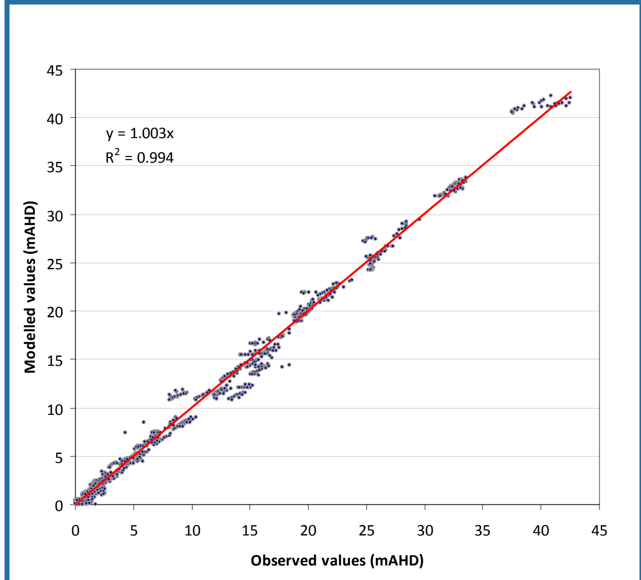


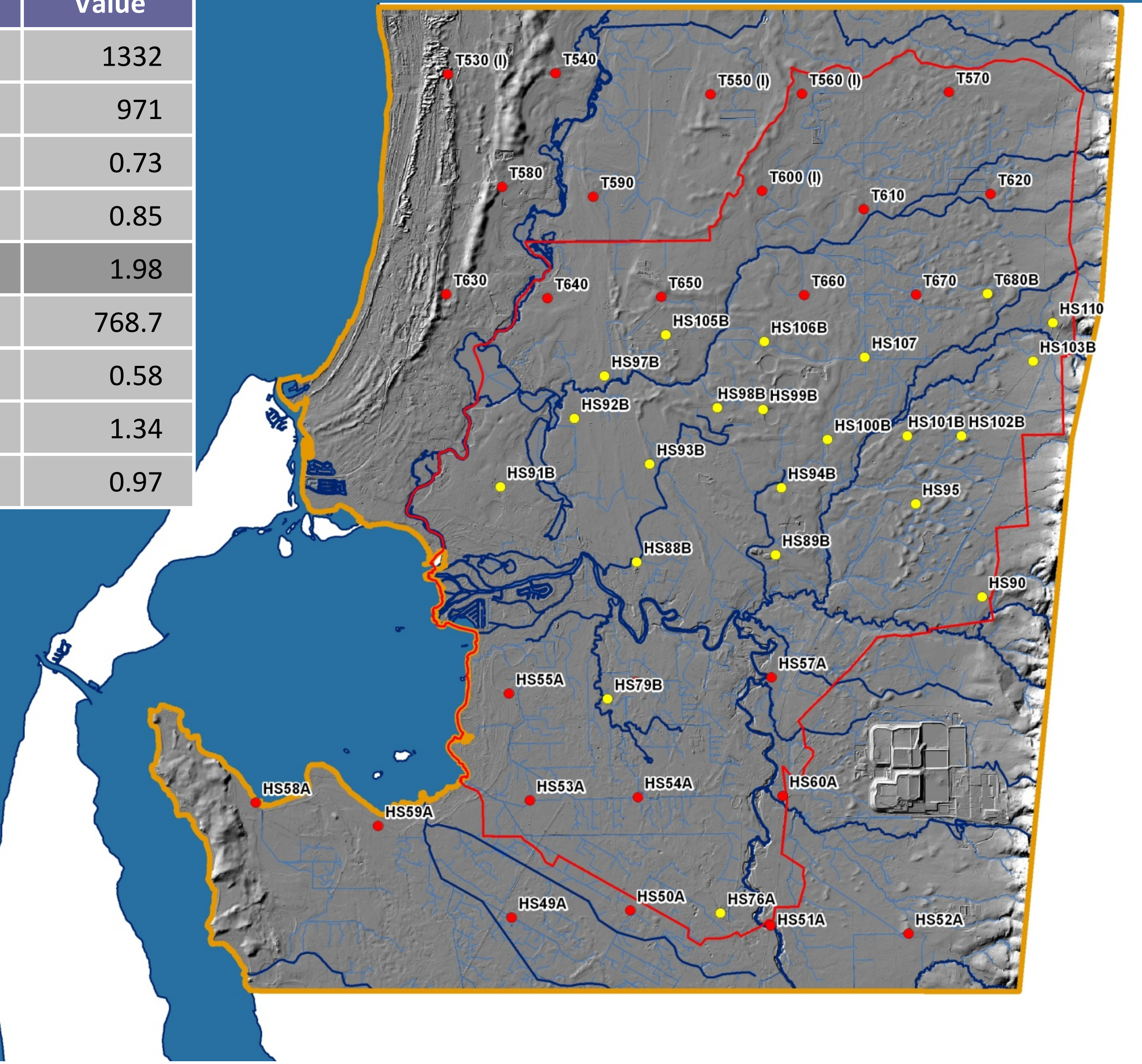
Murray (WA) MIKE SHE

Model calibration/validation statistics

More than software...

Description	Symbol	Value
Count	n	1332
Sum of squares (m^2)	SSQ	971
Mean sum of squares (m^2)	MSSQ	0.73
Root mean square (m)	RMS	0.85
Scaled root mean square (%)	SRMS	1.98
Sum of residuals (m)	SRMS	768.7
Mean sum of residuals (m)	MSR	0.58
Scaled mean sum of residuals (%)	SMSR	1.34
Coefficient of determination ()	CD	0.97





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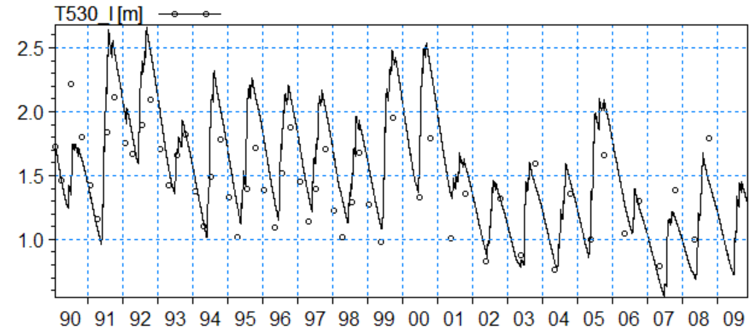
Murray Model Calibration/Validation

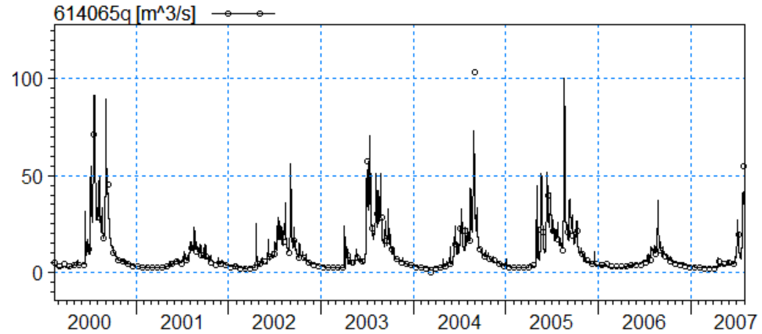
More than software...

Groundwater calibration example

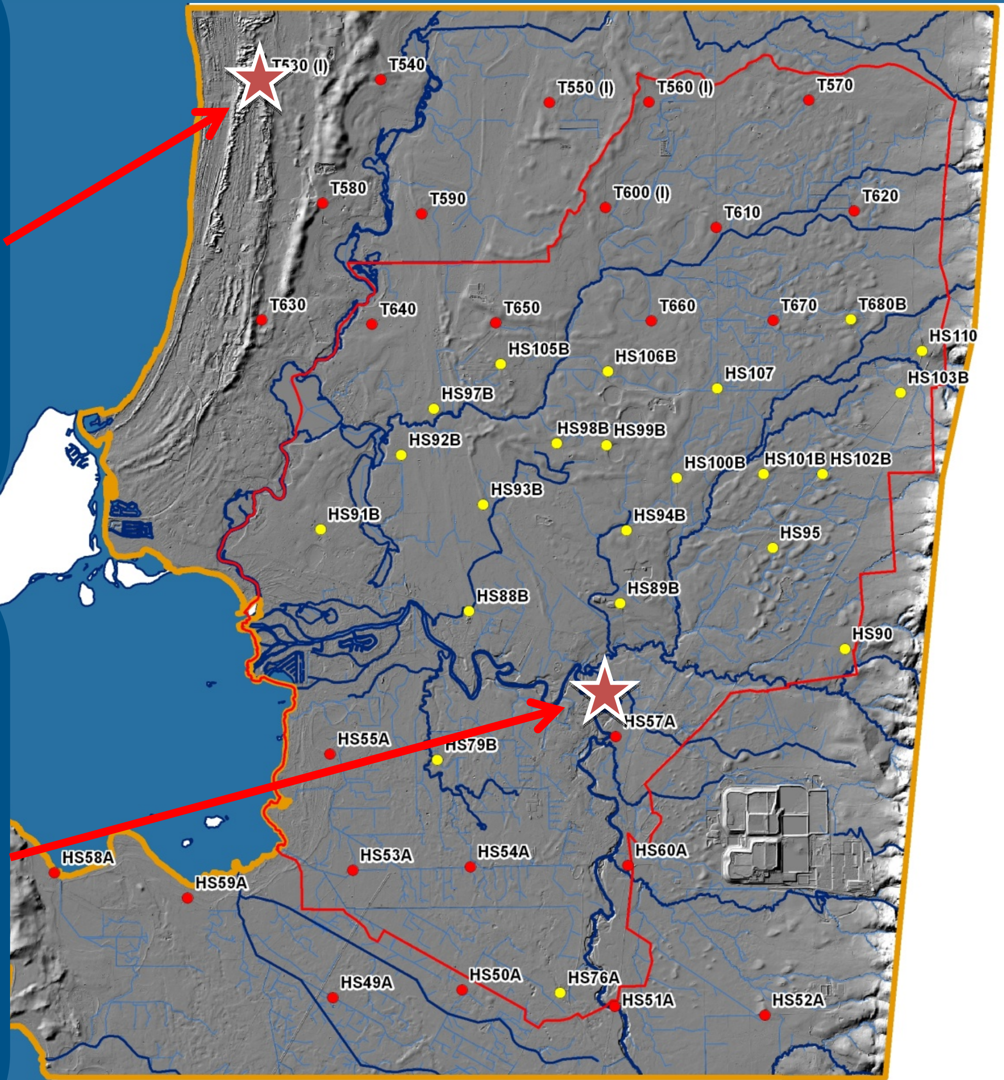


ME=-0.0504332
MAE=0.165029
RMSE=0.21504
STDres=0.209042
R(Correlation)=0.878955
R2(Nash_Sutcliffe)=0.616706

Surface water calibration example



ME=0.806563
MAE=2.5912
RMSE=7.2717
STDres=7.22683
R(Correlation)=0.959799
R2(Nash_Sutcliffe)=0.871525



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Scenarios

More than software...

Model was used to determine groundwater levels, and surface water /drainage flows under a range of:

- **Climate scenarios (dry, medium and wet from IPCC)**
- **Development scenarios (varying fill levels, drain levels, abstraction regimes)**