IN THE MATTER OF	the Resource Management Act 1991
AND	
IN THE MATTER OF	applications by Central Plains Water Trust to: Canterbury Regional Council for resource consents to take and use water from the Waimakariri and Rakaia Rivers and for all associated consents required for the construction and operation of the Central Plains Water Enhancement Scheme Selwyn District Council for resource consents to construct and operate the Central Plains Water Enhancement Scheme
AND	
IN THE MATTER OF	a notice of requirement by Central Plains Water Limited to: Selwyn District Council for the designation of land for works associated with the construction and operation of the Central Plains Water Enhancement Scheme

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SUPPLEMENTARY EVIDENCE OF JULIAN JAMES WEIR

INTRODUCTION

1. My full name is Julian James Weir. I have described my qualifications and experience in my main brief of evidence prepared for this hearing, though I now have one year additional experience in groundwater related research and consultancy and have undertaken ongoing training in groundwater modelling.

2. I have read the Code of Conduct for expert witnesses produced by the Environment Court in a practice note dated 31 March 2005 and I agree to comply with it.

Scope of Evidence

3. The purpose of this supplementary evidence is to present my assessment of the regional scale effects on groundwater mounding, lowland stream flows and Lake Ellesmere groundwater inflows (seepage) from the revised Central Plains Water Enhancement Scheme (CPWES). The configuration and rationale of the revised scheme are described in the evidence by Mr. Tipler and I have not reproduced this information herein except where required for explanation of the groundwater modelling.

Development Scenarios Considered and Work Undertaken

4. The proposed revised scheme does not include the storage reservoir and relies on the use of existing groundwater consents to make up the short fall of unreliable run of river takes for half of the scheme. Throughout this evidence I refer to this scenario as ‘CPWES No Dam’. This is in contrast to the previous scenario that included a storage reservoir, which in my previous evidence I referred to as ‘CPWES’. The ‘Status Quo’ scenario referred to in this evidence is the same as in previous evidence.

5. On 29 June 2009, Cliff Tipler (URS), Walter Lewthwaite (URS) and I met with Howard Williams (ECan), David Scott (ECan) and Peter Callander (PDP) to discuss how to address groundwater aspects of the Request for Further Information from the Commissioners dated 18 May 2009. At this meeting, the following action relating to groundwater modelling was agreed:

   - There was insufficient time to allow the running of the transient groundwater model for the full 40 years simulation. Therefore, the model would be run for the first 10 years (approximately). Subsequent to the meeting, the model was set up and run for the first 12 years of the simulation (1 June 1967 through to 1 June 1979). This period includes the same representative wet and dry periods as presented in my previous evidence, but not the average year.

- Stream flow statistics from the shorter-period groundwater model runs would be compared with results from earlier runs to interpret the scale of predicted effects for the 40-year period.

- ECan staff and Mr. Callander requested that eigenmodels for several representative wells over the Central Plains be constructed and used to cross check the predicted results from the numerical model. The eigenmodels would be used to compare both mounding predictions and stream flow change predictions. A correlation between groundwater levels and representative streams would be used for the latter.

6. The following presents a description of this work, the results, and comparisons with equivalent previous modelling predictions.

SUMMARY OF KEY FINDINGS

7. A new development scenario, CPWES No Dam', has been simulated and compared with the results from the 'Status Quo' and 'CPWES' model simulations.

8. Based on results from the numerical model simulations, the predicted maximum mounding under the 'CPWES No Dam' scenario in a dry year is 6.5 m, which is approximately 60% of the maximum mound predicted under the 'CPWES' scenario (10.5 m). The overall spatial extent is also reduced. In a wet year, the maximum mound under the 'CPWES No Dam' scenario is approximately 7 m, which is approximately 90% of the 'CPWES' scenario prediction (7.5 m). Again, the overall spatial extent is less. The lesser mounding in a dry year compared to a wet year under the 'CPWES No Dam' scenario is due to the run of river restrictions imposed in (and leading up to) the dry year.

9. Compared to the 'CPWES' scenario, the total area that may experience additional shallow groundwater is approximately 20% less under the 'CPWES No Dam' scenario in a wet year, and approximately 30% in a dry year.

10. Lowland stream flows are predicted to increase under the 'CPWES No Dam' scenario (compared to 'Status Quo'), but the predicted increases are 9-60% less than predicted under the 'CPWES' scenario.

11. Eigenmodel predictions of maximum groundwater mounding in wells located inland and mid plains are typically greater than the numerical model (up to 2 times greater). For shallower locations towards the coast, there are still differences, but the magnitude of the differences are much less. If the Commissioners consider that the measures previously proposed to mitigate shallow groundwater level rises in the

lowland areas are suitable, then they are likely to remain suitable under the 'CPWES No Dam' scenario, regardless of the differences in predicted mounding in these areas.

12. Flow changes in the Avon River and Harts Creek were simulated using the eigenmodel. Predicted flow changes in these streams were larger than the predicted changes from the numerical model.

13. It is possible that the eigenmodels may present an upper bound to the predictions, but I consider this unlikely, primarily for the following reasons. Eigenmodels are simplistic in nature. They assume the multilayer aquifer system is a single 'bathtub'. They do not fully account for the regulating effects of the Waimakariri and Rakaia rivers (where these rivers interact with neighbouring groundwater along the sides of the plains), or the drainage characteristics of the Selwyn River as it passes through the middle of the scheme. Because of these, I consider that eigenmodels are likely to over predict the groundwater system response to the proposed scenarios. For the scenarios simulated, I consider a realistic groundwater system response will be closer to the predictions of the numerical model.

14. Aqualinc has recently added a new mass balance package to the FEMWATER modelling software which enables reporting of water accounting. Results from this indicate that changes to groundwater flow into Lake Ellesmere (seepage) will increase by approximately 0.4 m^3/s under the 'CPWES' scenario and 0.2 m^3/s under the 'CPWES No Dam' scenario (i.e. the increase is 50% less under the 'CPWES No Dam' scenario).

GROUNDWATER MOUNDING

15. Overall the increase in predicted groundwater levels under the revised 'CPWES No Dam' scenario is less than predicted previously under the full 'CPWES' scenario. Appendix A presents modelled contours of groundwater mounding in Aquifer 1 for the dry and wet periods under the 'CPWES No Dam' scenario. For ease of comparison, mounding predicted under the original 'CPWES' is also presented, reproduced from my main evidence.

16. Consistent with previous modelling, the predicted groundwater mound is greatest towards the south-eastern (lower) boundary of the scheme away from the main rivers, and dissipates towards the coast and adjacent to the main rivers.

17. Under the 'CPWES No Dam' scenario, a maximum mound (in Aquifer 1) of approximately 6.5 m is predicted in the centre of the scheme area during a dry period. The status quo depth to groundwater at this location is approximately 20-30

m bgl. Under the 'CPWES' scenario, a maximum mound (in Aquifer 1) of approximately 10.5 m was predicted at the same location (paragraph 142 of my main evidence). The predicted maximum groundwater mound under the revised 'CPWES No Dam' scenario is therefore approximately 60% of the original scheme predictions in a dry period. The overall spatial extent of the mound is also reduced (refer to the maps in Appendix A).

18. During a wet period the maximum mounding (in Aquifer 1) predicted under the 'CPWES No Dam' scenario is approximately 7 m at a location where the status quo depth to groundwater is approximately 10 m bgl. This is approximately 90% of the maximum mound predicted under the 'CPWES' scenario (7.5 m; paragraph 144 of my main evidence). The overall spatial extent of mounding under the 'CPWES No Dam' scenario is also slightly less than under the 'CPWES' scenario.

19. Under the 'CPWES No Dam' scenario, the maximum mounding in a dry year is predicted to be slightly less than in a wet year. This is due to the run of river restrictions imposed in (and leading up to) the dry year, which does not influence the wet year to the same degree.

20. Due to time constraints, predictions for an average year have not been generated. However, it is expected that the relative differences will be consistent with the differences presented above for the wet and dry periods (i.e. 60-90% of the original). Given that the previous prediction of mounding in an average year was approximately 10 m (paragraph 143 of my main evidence), predicted mounding under the 'CPWES No Dam' scenario during an average year would be approximately 6-9 m.

DEPTH TO SHALLOW GROUNDWATER

21. Appendix B presents modelled contours of the depth to shallow groundwater. Maps for the 'Status Quo' and 'CPWES' scenarios have been reproduced from my original evidence to assist comparison.

22. The modelled areas where the depth to groundwater is less than or equal to 1 m, and less than or equal to 5 m, are shaded on the maps in Appendix B. The areas of these shaded zones between the Waimakariri and Rakaia rivers are summarised in Table 1 and Table 2. As stated in my original evidence, there is an unquantifiable level of uncertainty in the area of land where the depth to groundwater is shallow due to potential inaccuracies in the land surface elevations. However, as stated in my response to submitters (paragraph 14), the greatest accuracy of the model

predictions is gained from considering the predicted *changes* in effects between scenarios.

23. The total model area between the Rakaia and Waimakariri rivers is approximately 293,400 ha.

Table 1: Plan area of where the depth to shallow groundwater is 5 m or less between the Rakaia and Waimakariri rivers for each development scenario

Representative period	**Scenario**	**Area where groundwater is 5m depth or less (ha)**	**Area of increase between the SQ and CPWES scenarios (ha)**	**Increase between SQ and CPWES as a percentage of the total land area**
Dry (1 Mar 1970)	SQ	77,377	-	-
	CPWES No Dam	89,919	12,542	4.2%
	CPWES	97,285	19,908	6.7%
Wet (1 Oct 1978)	SQ	148,570	-	-
	CPWES No Dam	156,645	8,075	2.8%
	CPWES	159,215	10,645	3.6%

Table 2: Plan area of where the depth to shallow groundwater is 1 m or less between the Rakaia and Waimakariri rivers for each development scenario

Representative period	**Scenario**	**Area where groundwater is 5m depth or less (ha)**	**Area of increase between the SQ and CPWES scenarios (ha)**	**Increase between SQ and CPWES as a percentage of the total land area**
Dry (1 Mar 1970)	SQ	37,656	-	-
	CPWES No Dam	42,058	4,402	1.5%
	CPWES	44,269	6,613	2.3%
Wet (1 Oct 1978)	SQ	85,680	-	-
	CPWES No Dam	93,364	7,684	2.6%
	CPWES	95,181	9,501	3.2%

24. Based on Table 1, an additional 2.8-4.2% of the total land area between the Rakaia and Waimakariri rivers may experience shallow groundwater levels 5 m below ground level or less under the ‘CPWES No Dams’ scenario compared with the ‘Status Quo’. The total area that may experience additional shallow groundwater (5 m bgl or less) is approximately 20% less under the ‘CPWES No Dam’ scenario compared to the ‘CPWES’ scenario in a wet year, and approximately 30% less in a dry year.

25. Similarly from Table 2, an additional 1.5-2.6% of the total land area between the Rakaia and Waimakariri rivers may experience shallow groundwater levels 1 m below ground level or less under the ‘CPWES No Dams’ scenario compared with the ‘Status Quo’. The total area that may experience additional shallow groundwater (1 m bgl or less) is also approximately 20% less under the ‘CPWES No Dam’ scenario compared to the ‘CPWES’ scenario in a wet year, and approximately 30% less in a dry year.

26. Appendix C presents maps showing the modelled spatial extent of changes in shallow groundwater between the ‘CPWES No Dam’ and the ‘Status Quo’ scenarios for both cases where the depth to shallow groundwater is less than or equal to 1 m, and less than or equal to 5 m. Differences for the ‘CPWES’ scenario are also provided, reproduced from my original evidence (for comparison). As discussed in my original evidence, the increases in shallow groundwater occurs in areas where groundwater is naturally shallow under the ‘Status Quo’ scenario, and in areas adjacent to the Selwyn River.

LOWLAND STREAM FLOWS

27. Appendix D presents stream flow statistics for all three scenarios for the first 12 years of the model simulation period (1967-1978). Values for the ‘Status Quo’ and ‘CPWES’ scenarios differ from the equivalent values presented in Appendix L of my main evidence as the model period is different (40 years versus 12 years). The values presented in Appendix D show how the predicted lowland stream flows vary under the ‘CPWES No Dam’ scenario compared to the ‘CPWES’ scenario. Appendix E presents the same stream flow statistics but for the full 40-year model period. The values for the ‘Status Quo’ and ‘CPWES’ scenarios have been reproduced from Appendix L of my main evidence. The values for the ‘CPWES No Dam’ scenario have been interpolated (pro rata) from the other scenarios and the values in Appendix D.

28. Based on the values in Appendix D, the increases in lowland stream flows (over and above the ‘Status Quo’ scenario) are 9-60% less under the proposed revised scheme than predicted under the original scheme.

EIGENMODELLING

29. As discussed in paragraph 5, ECan staff and Mr. Callander requested eigenmodelling be undertaken as an independent check of the predictions of the numerical model. Eigenmodelling was presented in evidence by Mr. Scott and Dr. Bidwell. I have reservations regarding the use of eigenmodels in this application which I discussed in paragraph 16 of my Response to Officers’ Supplementary Reports and Submitters’ Reports. In summary, my reservations were:

- Eigenmodels are a highly simplified representation of the complex groundwater system.
- They assume the aquifer is a single layer and therefore cannot simultaneously represent multiple layers.
- They assume river recharge is constant and do not allow for temporal variation.
- Eigenmodels do not allow for correlation between aquifer system inputs, and the rebalancing that occurs when a part of the system is changed.
- There is no separation between off shore discharge and lowland stream flow discharge, and therefore the relationship between the two is removed.

30. There are two additional points of reservation in paragraph 16 of my Response, which I now no longer hold concern over. These are:

- The eigenmodel method supplied by Dr. Bidwell now provides for broad spatial variation in land surface recharge and groundwater abstraction.
- As an analytical model, the eigenmodel does not require the maintenance of water budgets.

31. I will further discuss my opinion on the relevance of the eigenmodelling to the CPWES later in this evidence.

32. To further my understanding of eigenmodel principles and the specific application to Central Canterbury aquifers, I met with Dr. Bidwell and exchanged several subsequent emails in preparation of the work presented below. I also exchanged emails with Mr. Callander and ECan staff to refine the information they were seeking.

The assistance of Dr. Bidwell, Mr. Callander and ECan staff was useful, and I am particularly grateful to Dr. Bidwell for his contribution.

Summary of Dr. Bidwell's Central Canterbury Eigenmodels

33. Conceptually, Dr. Bidwell's eigenmodel representation of the Central Canterbury plains aquifer system consists of a simple rectangular, single layer model. The inland boundary is no-flow and the opposite (lower) boundary consists of a fully penetrating water body (such as the sea or a stream). The model is assumed to be fully isotropic and homogeneous. Aquifer flow is assumed to travel in the longitudinal direction (i.e. 1-dimensional flow) and therefore lateral boundaries are not specified.

34. Key factors in constructing an eigenmodel at a given location are:

- The total length (L) of the model in the direction of flow (L) and the location of the bore being matched (x) from the inland boundary. Specifically, the dimensionless ratio of x/L is considered, which is always a value between 0 and 1.
- The bulk aquifer storage (S).
- The bulk aquifer transmissivity (T) of the entire multilayer aquifer system (this can be estimated by summing the individual transmissivities of all layers). More specifically, the ratio of T/SL^2 is calibrated, which acknowledges the link between S and T in aquifer dynamics.
- For the models used herein, groundwater recharge from the main rivers is assumed to be constant and is modelled as a constant base groundwater level (River H). However, I do understand that a time series of variable river recharge can be specified, if known.
- Given a constant river-supplied groundwater level, the transient variations of groundwater levels are assumed to be due entirely to land surface recharge (LSR) effects and pumping superimposed onto the river-supplied base groundwater level.
- Multiple zones of differing LSR can be included (if desired) distributed evenly within each zone along the length L.
- Storage in the vadose zone is provided, which smooths and delays the LSR effect depending on the vadose zone storage time (Tv) for each LSR zone.
- Pumping is assumed to occur without smoothing or delay directly from the aquifer, and is specified as negative LSR. As the eigenmodels assume a single

layer aquifer system, the effects of pumping are realised instantaneously throughout the entire model.

- Recharge from the smaller rivers are ignored, though by default, this recharge signature may be included in the overall LSR effect, if both are dominated by rainfall.

Eigenmodel Calibration

35. In total, eigenmodels were constructed for 8 representative wells over the Central Canterbury plains, the locations of which are presented in Figure 1.

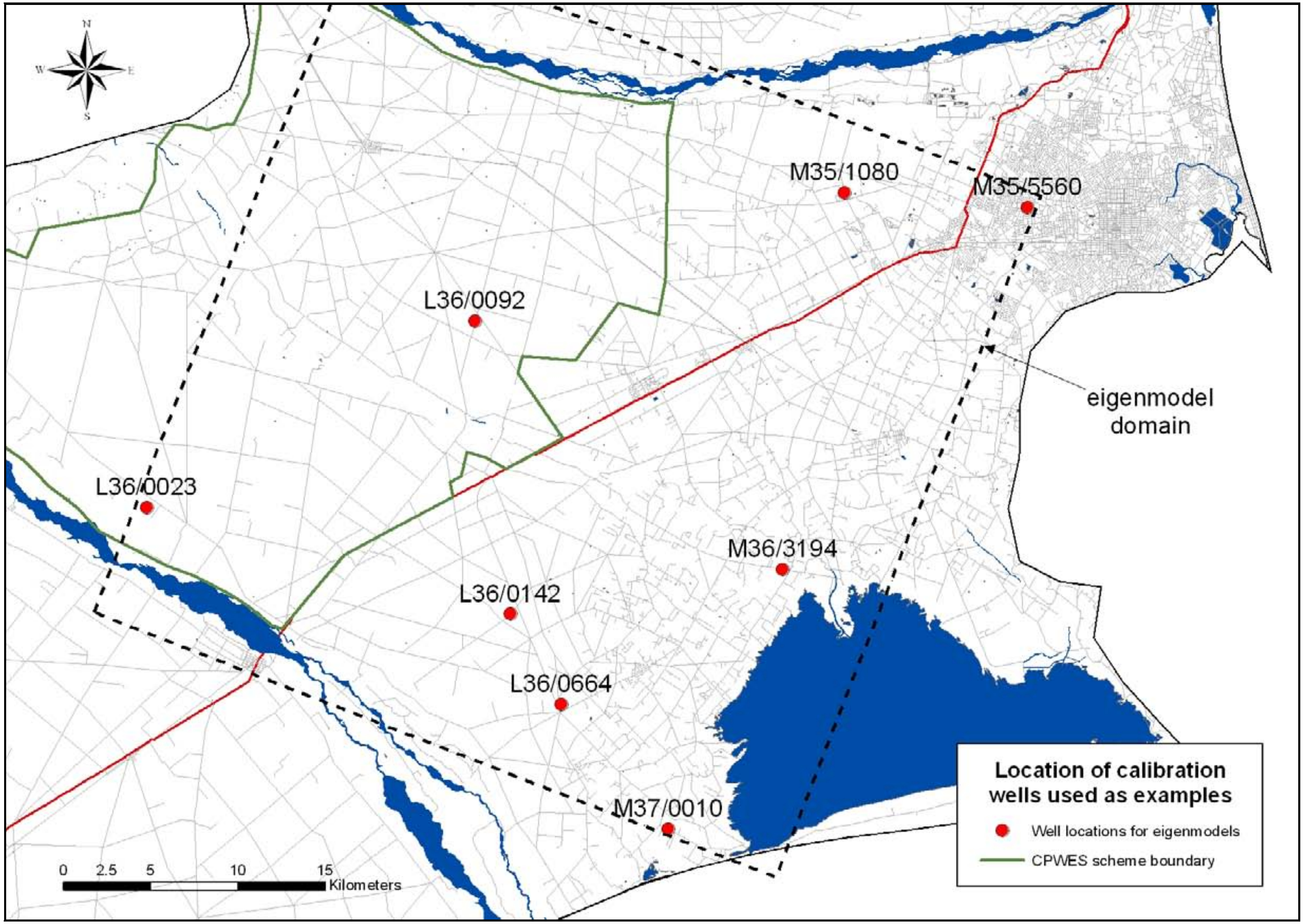

Figure 1: Locations of representative wells and domain used to construct eigenmodels

36. All wells (Figure 1) were chosen for their long length of measured groundwater levels and have been used as part of calibrating the numerical groundwater model. Wells L36/0023, L36/0092, L36/0142 and M35/1080 were selected to represent the overall state of the aquifer system. In addition, L36/0142 was chosen for its correlation with Harts Creek flow (Dr. Williams, pers. comms.). M35/5560 was chosen for its correlation with Avon River flows. Wells M36/3164 and L36/0664 were chosen to represent the lowland farming area and well M37/0010 was chosen to represent the coastal area.

37. Initially, individual eigenmodels were constructed for each well using the same LSR and pumping time series used in the numerical groundwater model at measured x/L locations for each well. An earlier period of the measured data was assigned to calibration, and a latter period for verification. Very good comparisons between measured and modelled groundwater levels were obtained, though it was found that a larger number of parameter combinations could be used to generate an equally good fit; the models were highly non-unique.

38. In addition, some wells (particularly those lower down the plains) could be fitted very well to measured data but the bulk aquifer transmissivity value was unrealistically high. For example, calibrated bulk aquifer T values in the order of several hundred thousand m^2/day were being generated, whereas values in the order of ten times less would be expected (based on results from aquifer tests such as those listed in Appendix C of Aqualinc, 2007[1]). Through email discussions with Dr. Bidwell regarding this, I found that calibrating the location of the well relative to the model length (i.e. the x/L parameter) enabled more realistic aquifer parameters. However, in some cases, this would then result in the calibrated location of the well being at an unrealistic distance from its measured position. Poor fits resulted if the wells were fixed at their individual measured locations and reasonable aquifer transmissivity used.

39. Dr. Bidwell explained how the unrealistic (x/L) parameter is compensating for the real aquifer not being a simple rectangular shape. I found that for some wells it was not possible to have both realistic aquifer parameters and realistic well locations within the same eigenmodel. For example, using a realistic value of T/SL^2 resulted in a modelled amplitude of change that was much larger than measured. To counter this, the well could be moved closer to the discharge boundary, which regulated its amplitude of change, but the modelled location was unrealistic compared to actual.

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[1] Aqualinc (2007): Canterbury Groundwater model 2. Report No L07079/1. July 2007. Aqualinc Research Ltd.

40. To reduce non-uniqueness of the calibration, all wells were linked to the same aquifer parameters and vadose zone storage time values while calibrating the location parameters (x/L) specific to each well. This was a recommendation by Dr. Bidwell and enabled consistency between wells in the same aquifer system. In doing so, a simplistic representation of the complex aquifer system was maintained, which is consistent with the eigenmodel approach. It did, however, reduce the overall fit with measured groundwater levels, but not by much. It also reduced model non-uniqueness, but again, not by much. The domain of the eigenmodels are shown in Figure 1.

41. The overall calibration process resulted in the parameters listed in Table 3. The resulting T values in Table 3 have been converted to an equivalent conductivity (K) value by dividing T by the approximate average thickness of the numerical model. For comparison, the horizontal conductivity (K) of the numerical model is in the range 5-2,400 m/day and storativity (S) 0.000015-0.01 (Appendix V of Aqualinc, 2007). The measured and calibrated x/L values are also provided for comparison. It was found that the overall calibration process was relatively insensitive to the vadose zone parameters (Tv)

Table 3: Eigenmodel calibrated parameters

Well		**L36/0023**	**L36/0092**	**L36/0142**	**L36/0664**	**M35/1080**	**M35/5560**	**M35/3194**	**M37/0010**
Approx. measured x/L		0.01	0.34	0.53	0.64	0.75	0.99	0.94	0.83
Calibrated x/L		0.10	0.10	0.77	0.90	0.91	0.97	0.93	0.98
River H (m)		79.9	61.5	36.5	21.7	44.7	12.9	3.4	6.0
Bulk T/SL^2 (day^{-1})		0.0215							
Bulk S		0.026							
L (km)		40							
Resulting Bulk T (m^2/day)		29,400							
Equiv. bulk K (m/day)[1]		110							
Vadose Zone Tv (months)	**Zone 15 and 19**	18							
	Zone 14 and 18	12							
	Zone 13 and 17	5							
	Zone 16	2							

[1] assuming a total aquifer thickness of 250 m, which is the approximate average thickness of the numerical model.

42. Plots of measured versus modelled groundwater levels are presented in Appendix F. For comparison, equivalent plots of measured versus modelled groundwater levels for the numerical model are presented in Appendix G (reproduced from Aqualinc, 2007). The combined calibration statistics of the eight eigenmodel wells are summarised in Table 4. Also included in Table 4 for comparison are the equivalent statistics for the transient numerical model (calibration period only), reproduced from Table 2 of my main evidence. The two sets of model calibration statistics are similar.

Table 4: Groundwater level objective function values and other statistics for the combined eight eigenmodels and also for the transient numerical model

Objective function or statistic	**Combined eigenmodels**	**Transient numerical model**
Mean error (ME)	-0.03 m	0.49 m
Normalised RMS	1.3%	1.1%
R^2 (square of the correlation coefficient)	0.998	0.997

Eigenmodel Scenarios

43. Once calibrated, the eight eigenmodels were then used to run the ‘Status Quo’, ‘CPWES’ and ‘CPWES No Dam’ scenarios. This was achieved by replacing the ‘Calibration’ time series of LSR and irrigation with the ‘Status Quo’, ‘CPWES’ and ‘CPWES No Dam’ time series, respectively. The same times series used in the numerical model were applied to the eigenmodels.

44. Appendix H presents time series plots of each development scenario for each eigenmodel. Also plotted on the same graphs are time series of differences in predicted groundwater levels between the ‘Status Quo’ and ‘CPWES’ scenario, and the ‘Status Quo’ and ‘CPWES No Dam’ scenario. For comparison, equivalent plots are presented in Appendix I for predictions from the numerical groundwater model at each of the eight eigenmodel locations.

45. Some of the ‘CPWES No Dam’ groundwater levels in Appendix I fall below the ‘Status Quo’ levels during summer periods. This is because the existing groundwater takes are redistributed on the plains. There are no new groundwater takes simulated under the ‘CPWES No Dam’ scenario (compared to ‘Status Quo’), but some existing

takes have been moved horizontally and vertically (deeper). For example, takes near the scheme periphery that currently take relatively shallow groundwater can supply some of that water from the scheme. Consequently, the unused groundwater can be used elsewhere further within the scheme where takes are deeper. The deeper takes particularly cause the small lowering of predicted summer groundwater levels because the storage coefficients of deeper aquifers are less than shallow.

46. A comparison of maximum and average predicted mounding is provided in Table 5 for the period 1967-1979 (this being the numerical model run period). The maximum mounding for bores L36/0023 and L36/0092 predicted by the numerical model is larger than the maximum mounding discussed in paragraphs 17 and 18. This is because the maximum mounding discussed in paragraphs 17 and 18 is for aquifer 1 and these two bores are located in aquifer 2 or below (where storage coefficients are smaller than the shallower aquifer).

Table 5: Comparisons of maximum and average predicted mounding (1967-1979)

Well	**Numerical model layer**	**Numerical model mounding (m)**		**Eigenmodel mounding (m)**		**Eigenmodel mounding compared to numerical model (%)**	
		CPWES-SQ	**CPWES No Dam - SQ**	**CPWES-SQ**	**CPWES No Dam - SQ**	**CPWES-SQ**	**CPWES No Dam - SQ**
Maximum groundwater mounding (1967-1979)							
L36/0023	Aquitard 2	10.5	10.0	17.0	13.5	162%	135%
L36/0092	Aquifer 2	9.4	8.8	13.6	8.9	145%	101%
L36/0142	Aquifer 1	3.0	2.4	6.1	4.9	203%	204%
L36/0664	Aquifer 1	1.8	1.6	3.1	2.4	172%	150%
M35/1080	Aquifer 1	1.7	1.6	1.7	1.1	100%	69%
M35/5560	Aquitard 1	0.6	0.6	0.5	0.3	83%	50%
M36/3194	Aquifer 1	1.3	1.1	2.1	1.7	162%	155%
M37/0010	Aquifer 1	0.9	0.8	0.4	0.3	44%	38%
Average groundwater mounding (1967-1979)							
L36/0023	Aquitard 2	3.6	2.7	13.8	9.9	383%	367%
L36/0092	Aquifer 2	5.2	3.5	11.7	6.5	225%	186%
L36/0142	Aquifer 1	1.2	0.8	5.0	3.6	417%	450%
L36/0664	Aquifer 1	0.5	0.3	2.5	1.8	500%	600%
M35/1080	Aquifer 1	1.2	1.0	1.6	0.9	133%	90%
M35/5560	Aquitard 1	0.1	0.1	0.4	0.2	400%	200%
M36/3194	Aquifer 1	0.3	0.2	1.7	1.3	567%	650%
M37/0010	Aquifer 1	~ 0	~ 0	0.3	0.2	-	-

47. For wells located inland and mid plains (L36/0023, L36/0092, L36/0142), the eigenmodel predictions of mounding are typically greater than the numerical model. For the shallower locations towards the coast, there are still differences, but the magnitude of the differences are generally less. This is due to the regulating mechanisms of the lower boundary (i.e. the coast and lowland streams and drains for the numerical model and the constant head boundary for the eigenmodels). In some locations, the eigenmodels predict a slightly smaller mound than the numerical model. Reasons for the differences in predictions are discussed later in my evidence.

48. The eigenmodels have been used to predict changes in lowland stream flows as a result of the development scenarios considered. To generate a prediction of changes in stream flows using the eigenmodels, a correlation between groundwater levels and stream flows has been generated based on measured data. Appendix J presents these correlations for the Avon River with bore M35/5560 and Harts Creek with bore L36/0142. These are the only two streams considered with eigenmodelling. The Avon River was chosen to represent a lowland stream to the north of Banks Peninsula, within the Christchurch City area. Harts Creek was chosen to represent a lowland stream south of Banks Peninsula nearer Lake Ellesmere.

49. The groundwater level-stream flow correlations presented in Appendix J have been matched to the low flow (or base flow) components of the stream flow time series. This is expected to better reflect the contribution from groundwater (i.e. without the quick flow component).

50. Given the correlations between stream flows and groundwater levels in Appendix J, the eigenmodels have been used to generate flows in the Avon River and Harts Creek and changes in stream flows between development scenarios. These time series are presented in Appendix K. The equivalent information derived from the numerical model is presented in Appendix L.

51. Table 6 compares stream flow changes for the numerical model and the eigenmodels. The eigenmodels have been constructed on monthly time steps, so the generation of 7-day MALF values is not possible. Therefore, a comparison of maximum and average changes is presented. Also shown in Table 6 are the predicted flow changes as a percentage of the measured mean flow for each stream. The mean flow for the Avon River is 1,840 l/s and for Harts Creek is 1,350 l/s.

Table 6: Comparison of maximum and average predicted stream flow changes (with change as a percentage of mean flow shown in brackets)

Well	**Numerical model flow change (l/s)**		**Eigenmodel flow change (l/s)**	
	CPWES-SQ	**CPWES No Dam - SQ**	**CPWES-SQ**	**CPWES No Dam - SQ**
Maximum flow change				
Avon River	103 (6%)	97 (5%)	591 (32)	436 (24%)
Harts Creek	437 (32%)	378 (28)	768 (57%)	704 (52%)
Average flow change				
Avon River	81 (4%)	66 (4%)	508 (28%)	321 (17%)
Harts Creek	208 (15%)	160 (12%)	645 (48%)	527 (39%)

52. As was found with the groundwater mounding predictions, the eigenmodels predict a larger change in stream flows between development scenarios than the numerical model. The following paragraphs discuss the reasons for the differences.

Model Predictions: Which is Right?

53. Now that there are two models predicting different effects, which one is correct? Firstly, no regional model can accurately predict a response from a future change in water use. Apart from the uncertainties, simplifications and assumptions inherit in any model construction, the human factors of any future development scenario are assumed, and can vary from that assumption.

54. However, it is my opinion that the predictions from the numerical model will more realistically represent the system response from the given development scenarios (i.e. the actual response will be closer to the predictions of the numerical model than the eigenmodels for the tested development scenarios). It is possible that the eigenmodel predictions may present an upper bound to the predictions, but this is unlikely for the following reasons.

    - The eigenmodels are a very simplified view of reality. They assume 1-dimensional flow along a rectangular, single layer domain (i.e. a ‘bathtub’). However, in reality, the aquifer system is not regular and is comprised of multiple layers with interactions that vary spatially. The complex interactions between differing conductivity zones and aquifers is provided for by the numerical model but not in the eigenmodels.

- The side boundaries of the Central Plains area are the Waimakariri and Rakaia rivers, which regulate changes in groundwater levels relative to the distance from these features. Also, the Selwyn River passes through the middle of the scheme which also acts as a groundwater level regulator and a key discharge feature. The eigenmodels do not fully allow for these and will therefore over-predict the mounding effects.

- The eigenmodels assume a constant recharge (and resulting base groundwater level) derived from the alpine rivers. At times, the CPWES will divert water from the rivers, thereby reducing instream flows, which will result in reduced recharge from the rivers to groundwater. Also, groundwater levels rise due to irrigation which reduces the head gradient between the rivers and nearby groundwater, again reducing the losses from the rivers. Hence, the river recharge is not constant between scenarios. This hydraulic rebalancing is inherent in the numerical model. The eigenmodels do not account for this, and therefore groundwater mounding will be over predicted.

- The lower boundary of the Plains comprises a mixture of streams and drains, off shore subsurface flow and Lake Ellesmere. The groundwater discharge to these features is spatially varying and inherent in the numerical model. The eigenmodels assume a single line boundary that fully penetrates all layers with no distinction between subsurface and surface discharge. Consequently, the spatial variation in discharge cannot be simulated and the eigenmodels may either over predict, under predict or reasonably predict the mound, depending on the relative location to the assumed boundary.

55. The eigenmodels do calibrate well to measured groundwater levels, either equal to or better than the numerical model. This is expected as the eigenmodels are very simple with only one dynamic input (LSR). However, there are aspects other than the calibration fit that should be accounted for when comparing the reliability of predictions from the numerical and eigenmodels:

- The eigenmodels are designed for a single purpose, that is, to replicate groundwater levels at a specific location as a function of LSR (and pumping, which is simulated as negative LSR). Their best use is for simple, inexpensive and conservative predictions where there is no access to a more complex numerical model, and it does this well. However, the numerical model incorporates multiple purposes; it predicts groundwater levels, flows off shore, flows between aquifers, flows to and from streams (etc.), interactions between all hydrogeological components and maintains accounts of where the water came from and went to. It allows for the much more complex hydrogeology and rebalancing that occurs in reality, and it, too, does this well.

- As discussed in paragraphs 37-38, there is a strong potential for non-uniqueness in the eigenmodels. Similarly good fits can be achieved using a range of calibration parameters, with each combination potentially yielding a different prediction of effects. There is also potential for non-uniqueness in the numerical model. This has been quantified by the computer software PEST and other manual sensitivity work (paragraphs 92-114 of my main evidence) and the acceptable range of parameters is relatively narrow.
- The locations of boundaries used in the eigenmodels are not accurately known. Paragraph 37 discusses this further. The numerical model incorporates the measured location of all visible boundaries (rivers, streams, drains, lakes and sea level), except for the sub-surface off-shore boundary. The location of this boundary is unknown, which is common to both eigen and numerical modelling.
- The numerical model simulates the transfer of water from deep to shallow layers through irrigation return. The eigenmodels assume that water returns to the same (single) layer that it was pumped from. This may cause an over prediction of groundwater levels in deeper aquifers but may not affect predictions in shallower aquifers.

56. As an approximate secondary check on the scale of mounding predicted by the numerical model, a comparison between recharge and groundwater level change has been made. For this example, the groundwater level rise in bore L36/0092 between 1973 (when measured levels were vey low) to 1975 (when measured levels were relatively high) has been compared with the calculated LSR around and upgradient of the bore.

57. The average recharge over this period is approximately 16 m^3/s (calculated using the soil-water balance model described in Aqualinc, 2007) which is approximately 450 mm per year over an area of 111,000 ha. Over this same time period, L36/0092 rose approximately 10 m. This equates to a groundwater level response of 0.6 m per m^3/s of recharge.

58. The total additional average recharge under the ‘CPWES’ and ‘CPWES No Dam’ scenarios is approximately 6.4 and 5.8 m^3/s respectively (from model mass balances, discussed later in my evidence). This is approximately 330 and 300 mm per year over 60,000 ha (including by wash discharge, distribution channel losses etc.). From Table 5, the average mounding predicted in L36/0092 by the numerical model is 5.2

and 3.2 m respectively. These equate to groundwater level responses of 0.8 and 0.6 m per m^3/s of recharge, similar to the equivalent measured response.

59. These calculations are not intended to be accurate, but provide a ball park comparison between actual and predicted groundwater level response due to changes in land surface recharge. The check suggests that the numerical model is suitably replicating the measured changes in groundwater levels for the additional land surface recharge from the CPWES.

60. Any adverse effects need to be mitigated. The key potential adverse effects relating to groundwater mounding is rising groundwater levels in the lowland plains area. Mr. Lewthwaite has described the proposed mitigation measures, which include improving the ability of the existing drainage network to remove the additional groundwater. In these lowland areas, the predicted mounding effects from the eigenmodels under the ‘CPWES No Dam’ scenario are not too dissimilar to the effects predicted previously by the numerical model under the ‘CPWES’ scenarios (Table 5, bores M37/0010, M36/3194 and M35/5560), which Mr. Lewthwaite has based his mitigation on. Therefore, if the Commissioners consider that the mitigation measures previously proposed are suitable, then they are likely to remain suitable regardless of the predicted mounding differences between the numerical and eigenmodels.

MASS BALANCES. OVERALL SCHEME DRAINAGE AND LAKE ELLESMERE SEEPAGE

61. To quantify the predicted change of groundwater seepage into Lake Ellesmere, model mass balances have been prepared. In early 2009, a mass balance package was added to the FEMWATER modelling software which enabled the reporting of flow components of the entire model and of specified model sub zones.

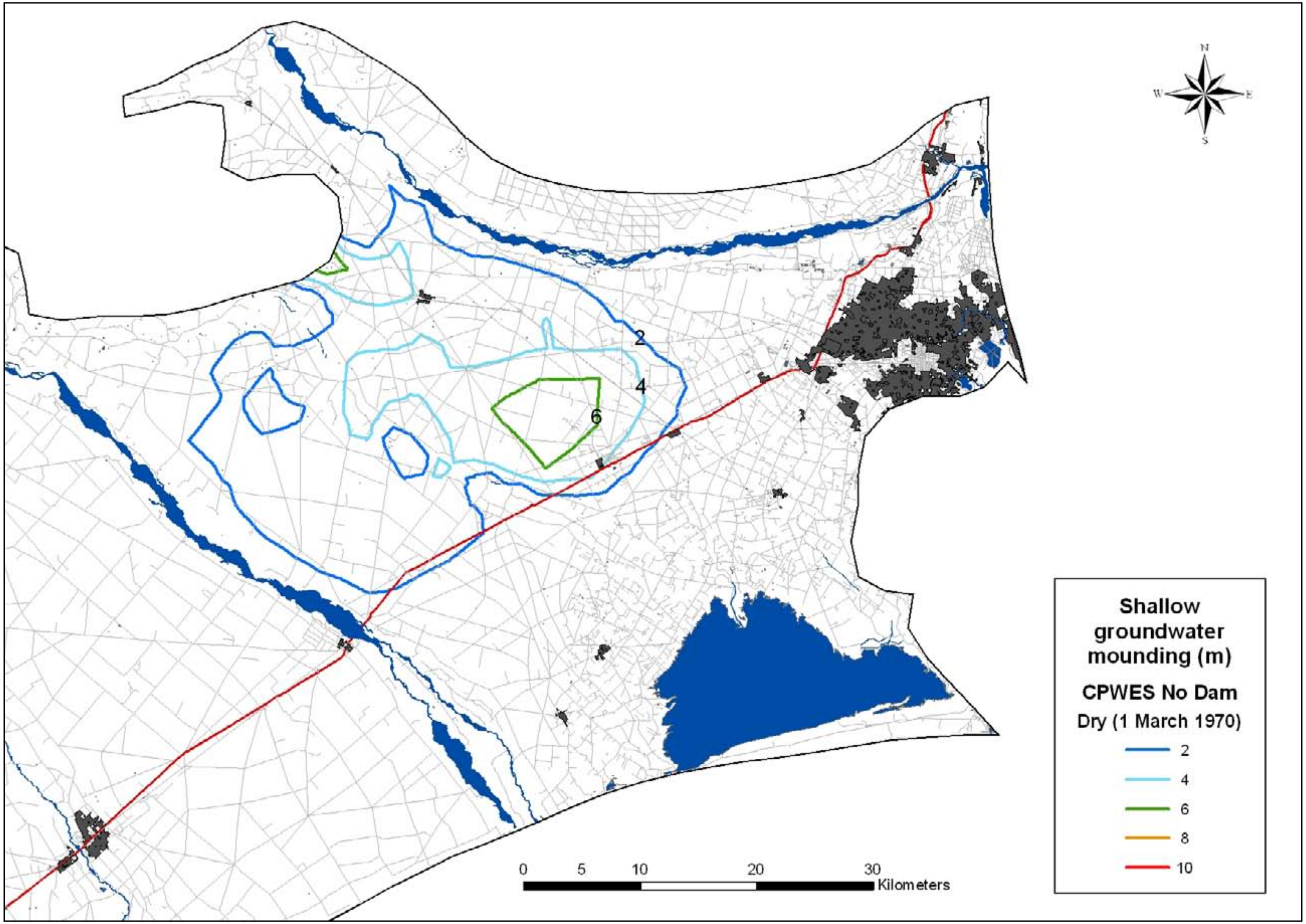
62. Appendix M presents total inflows and total outflows for the *entire* model (between the Waimakariri and Rangitata rivers) averaged over the first 12 years of the simulation (1967-1979) and for each of the three development scenarios considered. Mass balance differences between inflows and outflows range from 0.4-2.3%, which I consider small. The overall budget components are similar to those presented in Appendix O of my main evidence.

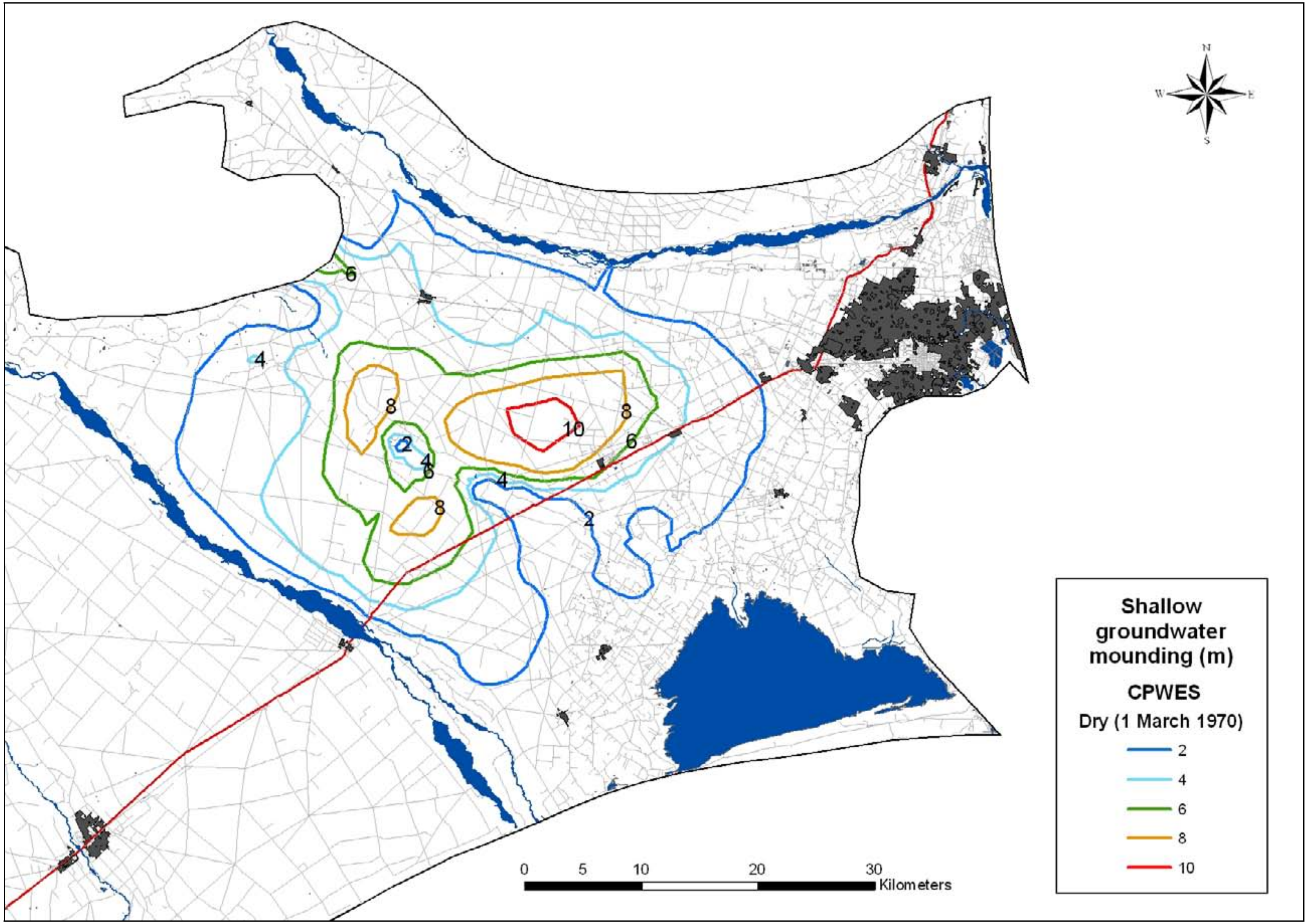
63. Compared to the ‘CPWES’ scenario, the ‘CPWES No Dam’ scenario results in less additional LSR to the groundwater system. This is why predicted mounding and stream flow changes are less than previously predicted. Given the mass balances in Appendix M, the average LSR for the period 1967-1979 increases by approximately

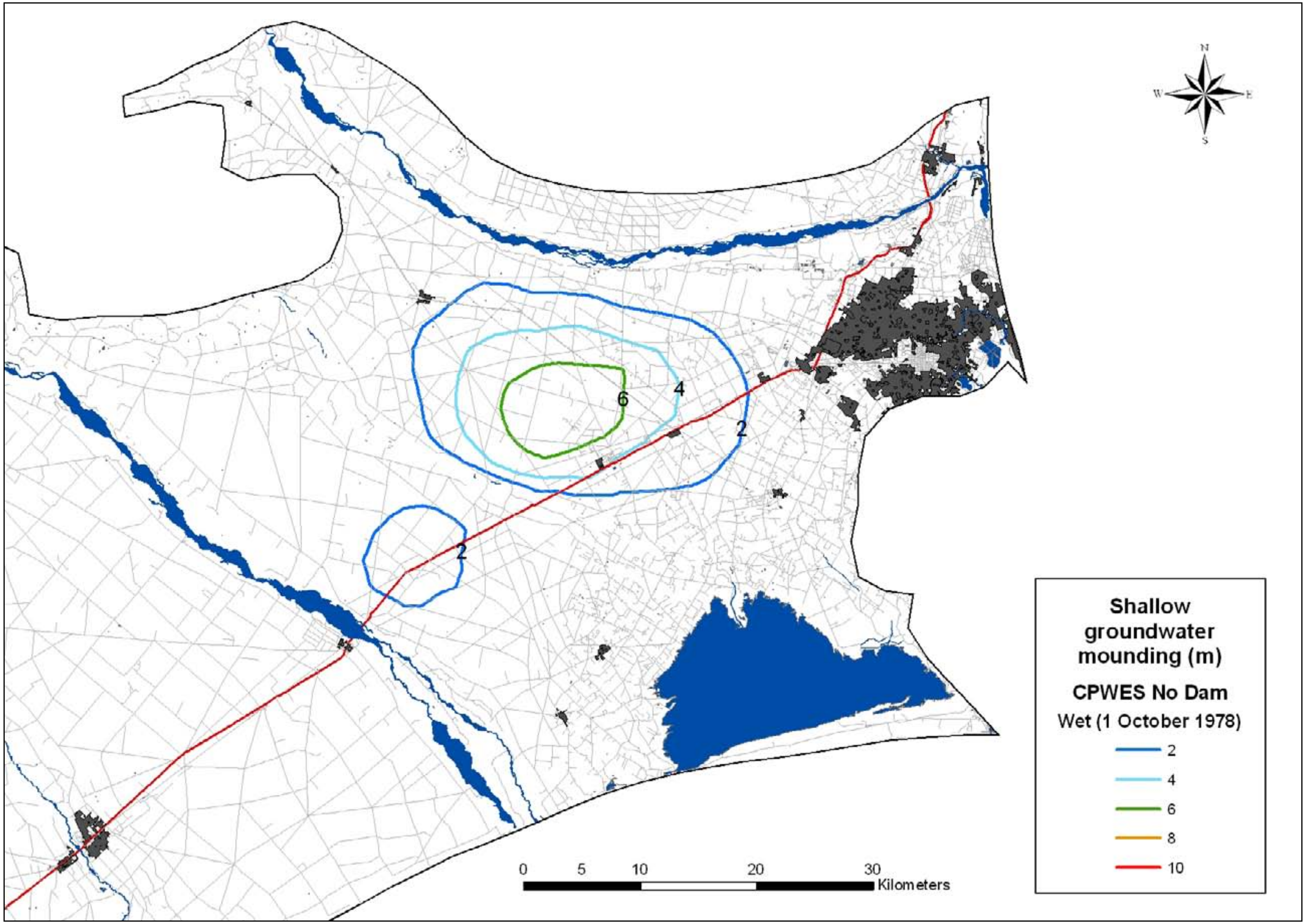
6.4 m^3/s as a result of the scheme. The increase under the ‘CPWES No Dam’ scenario is approximately 5.8 m^3/s, which is a reduction of 0.6 m^3/s (approximately 10%).

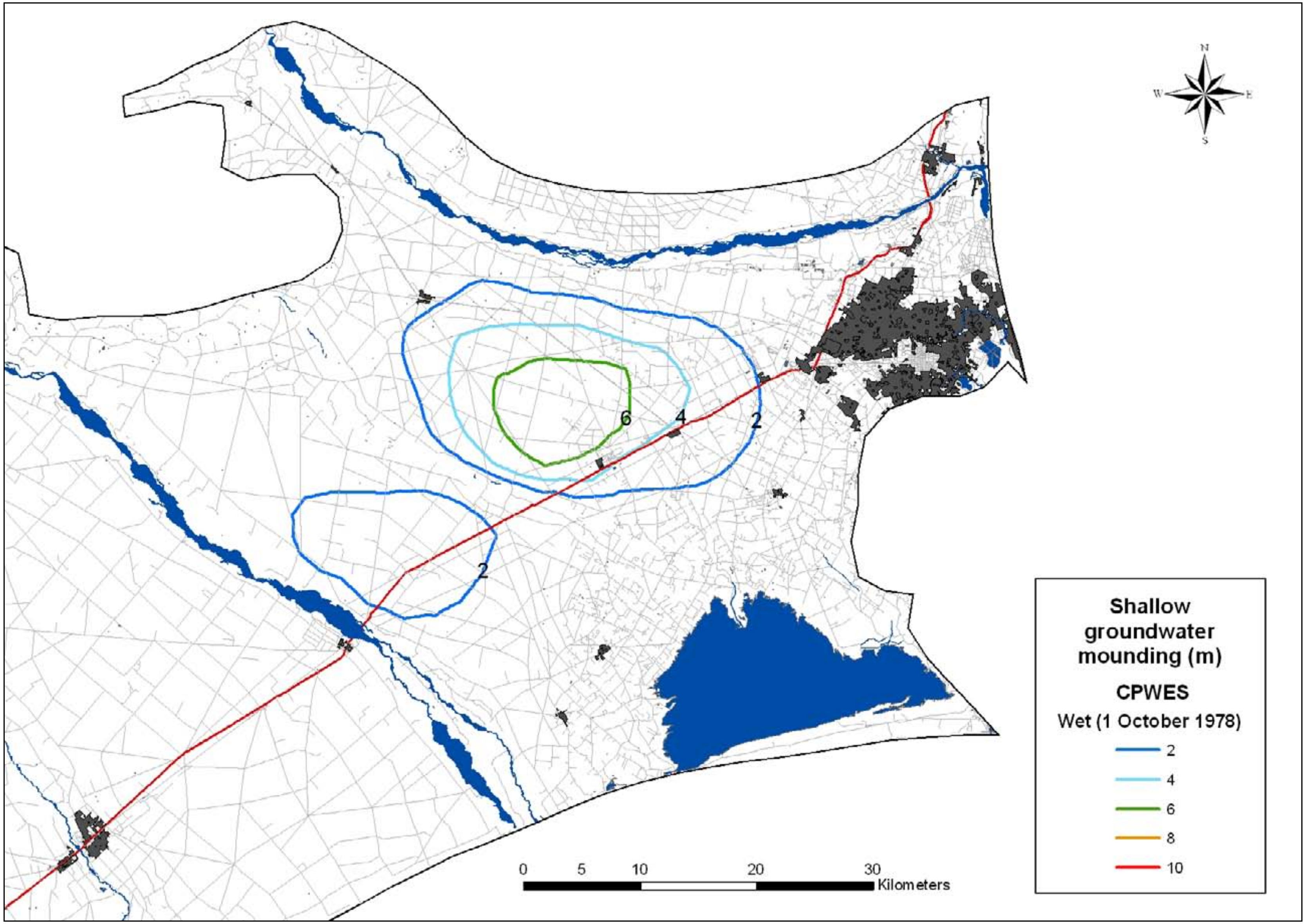
64. Based on the mass balances in Appendix M, groundwater seepage into Lake Ellesmere is predicted to increase from 13.1 m^3/s under the ‘Status Quo’ scenario to approximately 13.5 m^3/s under the ‘CPWES’ scenario, which is an increase of approximately 0.4 m^3/s. These values differ from Appendix O of my main evidence due to the new method of flow accounting using the mass balance package, and the shorter simulation run time. Under the ‘CPWES No Dam’ scenario, the predicted increase is approximately 0.2 m^3/s, which is 50% less than under the ‘CPWES’ scenario.

Appendix A: Groundwater level mounding in the shallow aquifer

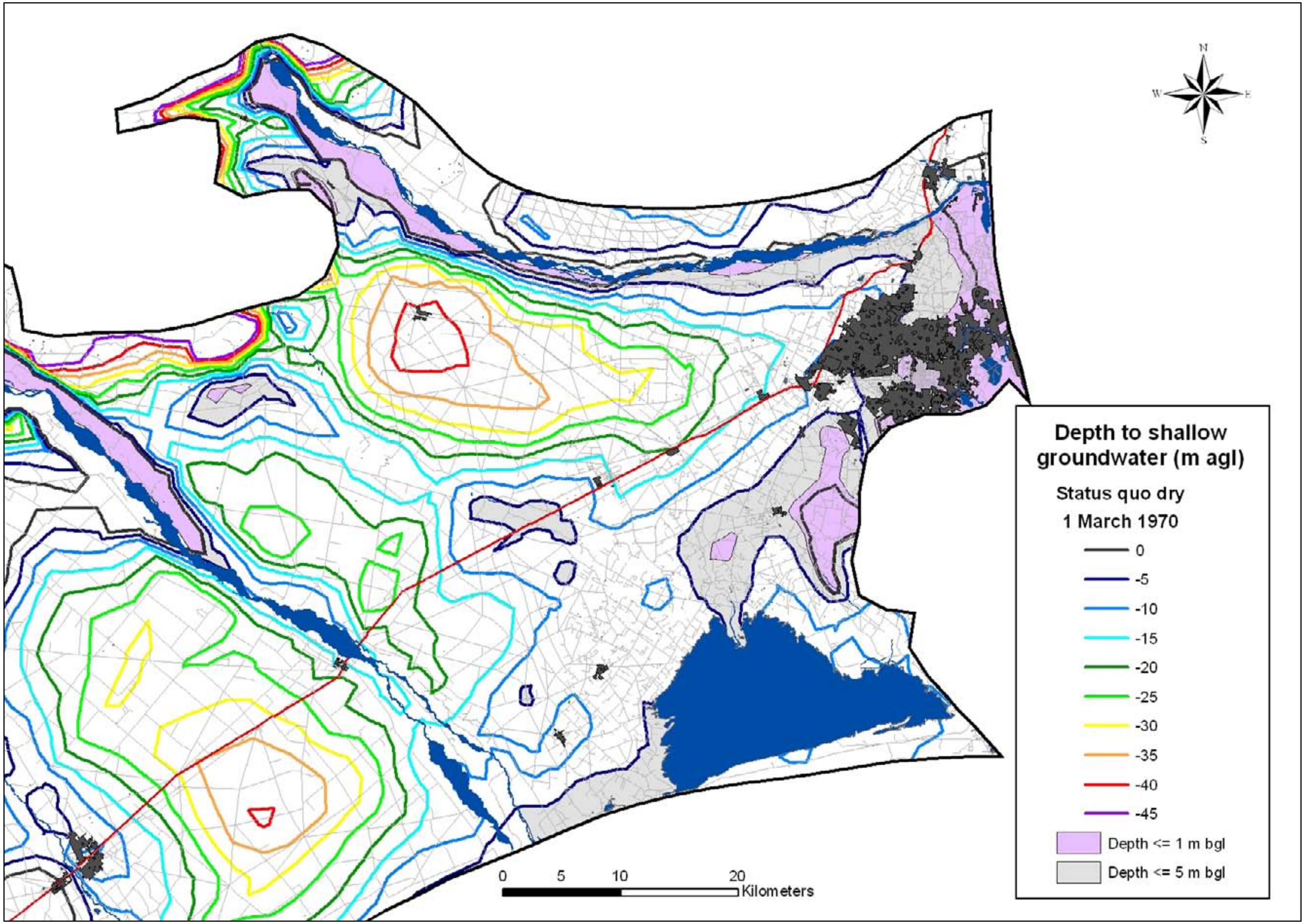

N
W
E
S
2
4
6
Shallow groundwater mounding (m)
CPWES No Dam
Dry (1 March 1970)
2
4
6
8
10
0
5
10
20
30
Kilometers

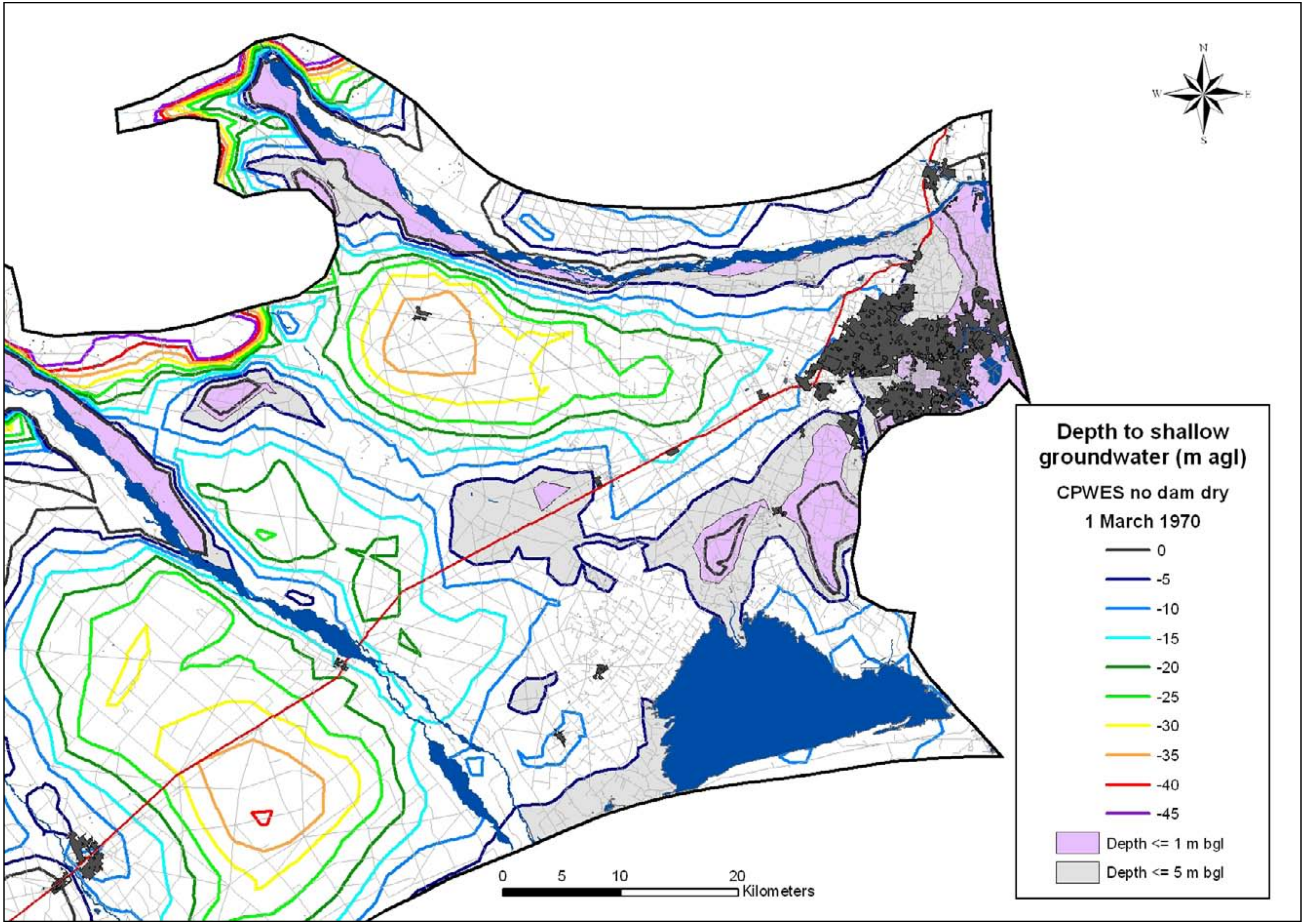

N
S
E
W
6
4
8
2
4
6
8
10
8
6
4
2
0
5
10
20
30
Kilometers
Shallow groundwater mounding (m)
CPWES
Dry (1 March 1970)
2
4
6
8
10

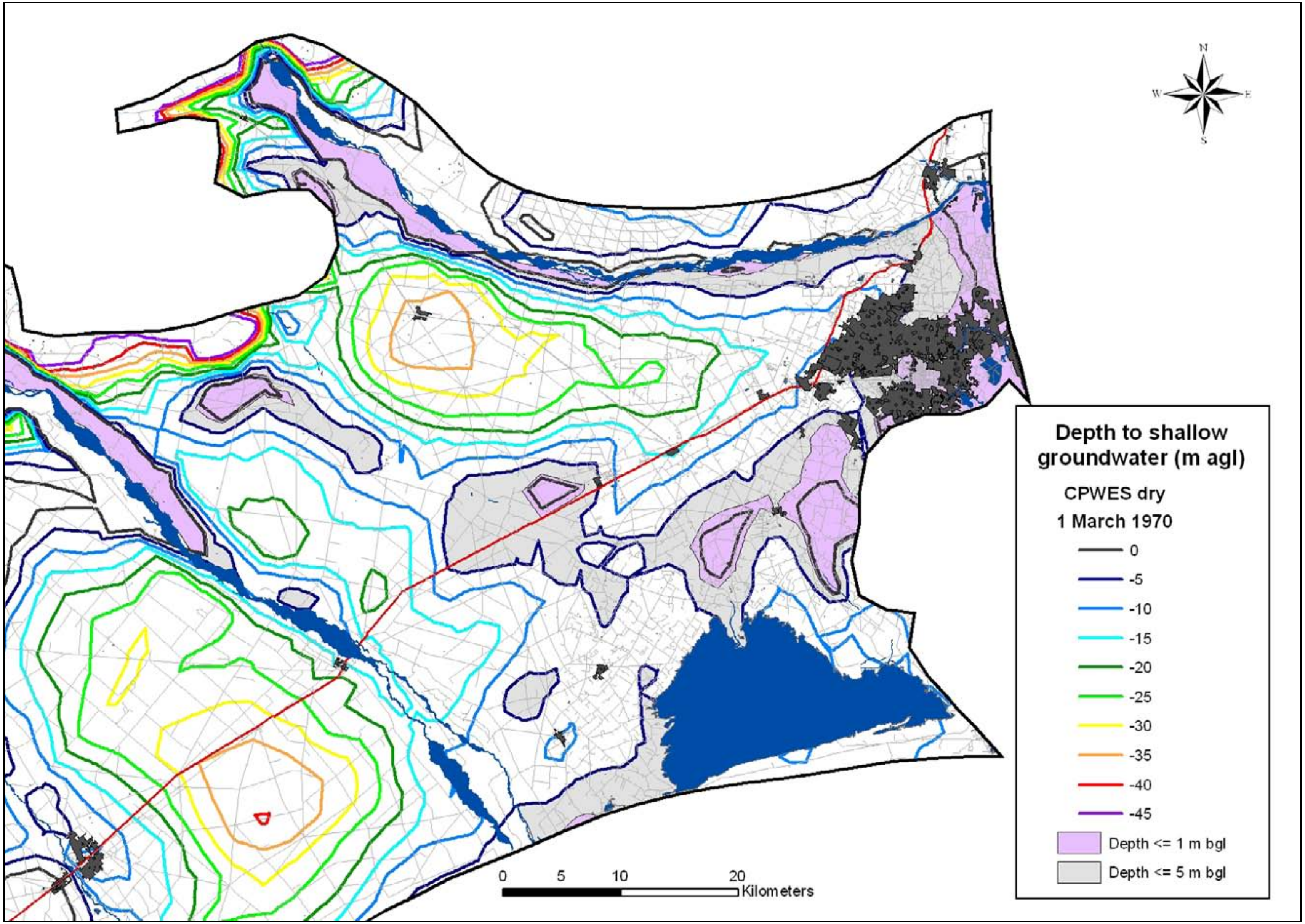

N
W
E
S
6
4
2
2
0
5
10
20
30
Kilometers
Shallow groundwater mounding (m)
CPWES No Dam
Wet (1 October 1978)
2
4
6
8
10

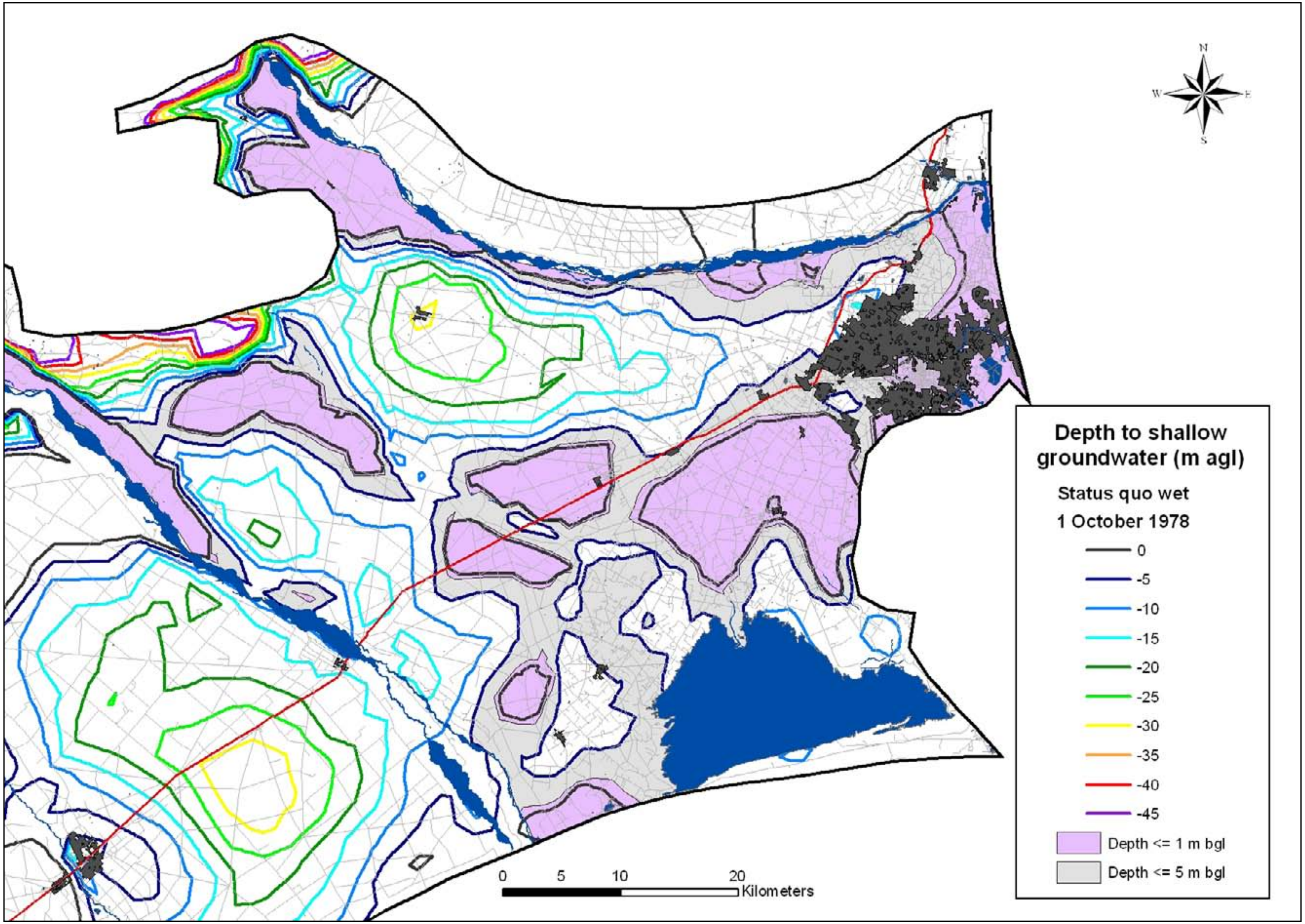

N
W
E
S
6
4
2
2
0
5
10
20
30
Kilometers
Shallow groundwater mounding (m)
CPWES
Wet (1 October 1978)
2
4
6
8
10

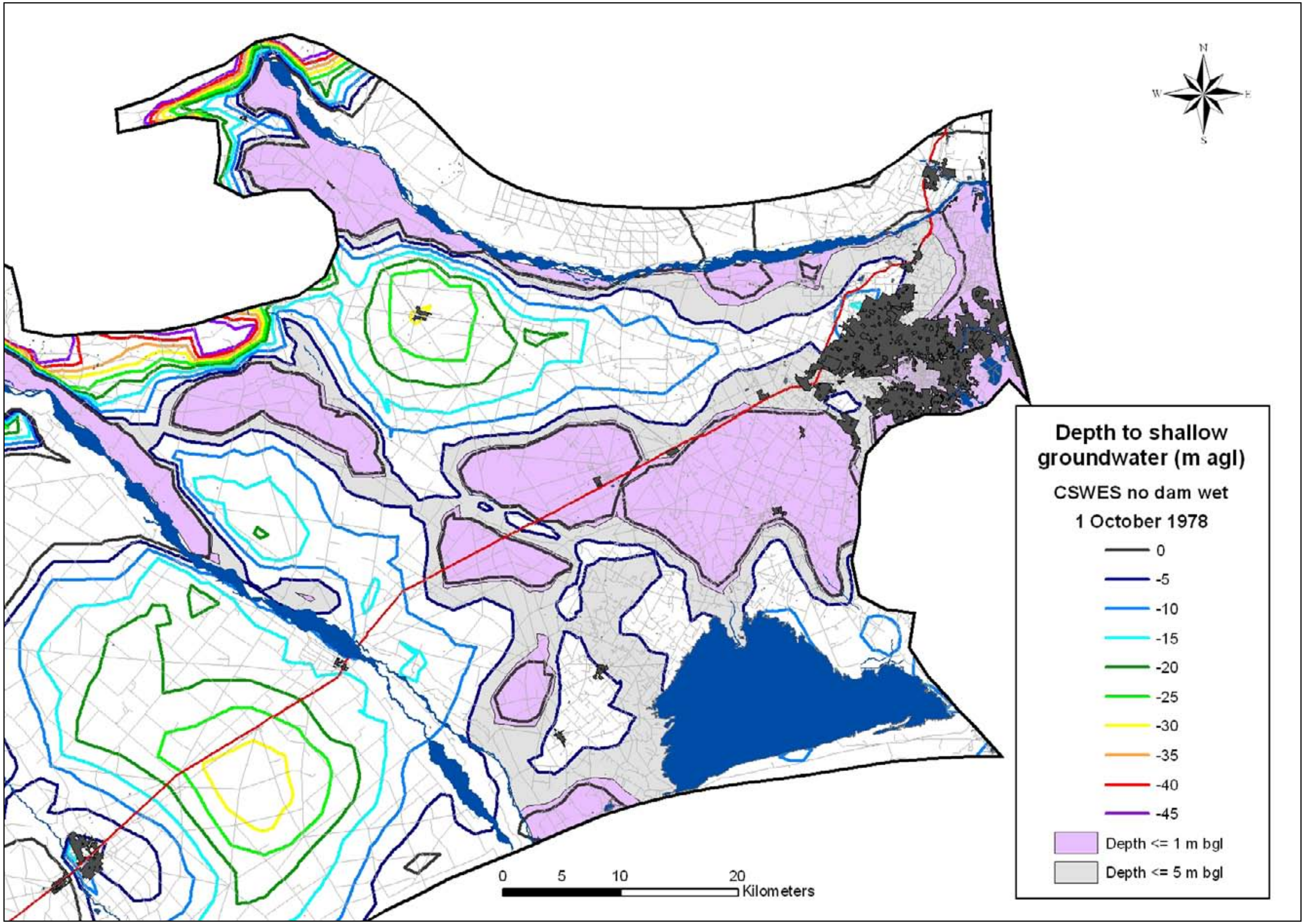
Appendix B: Contours of depth to shallow groundwater

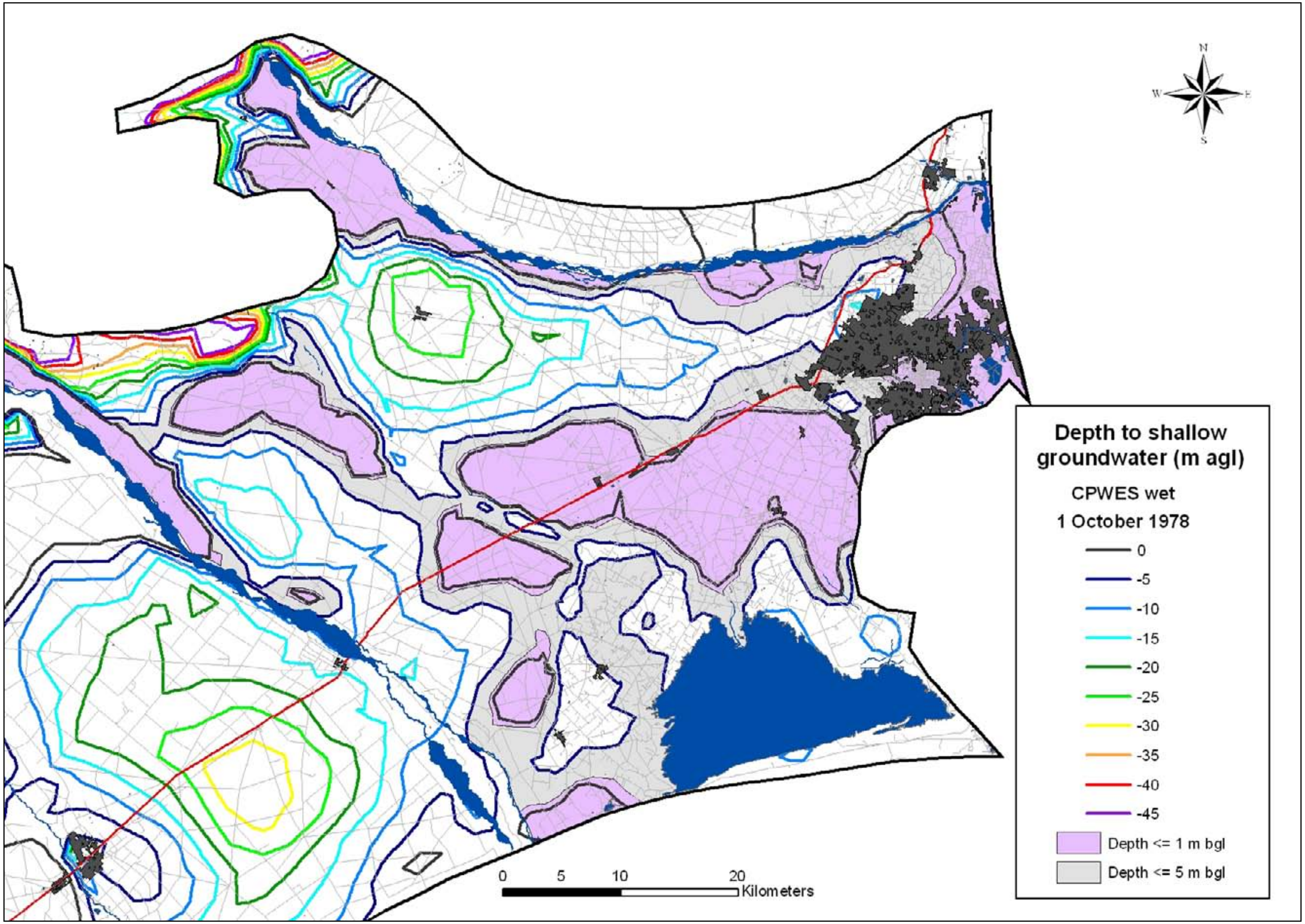

Depth to shallow groundwater (m agl)
Status quo dry
1 March 1970
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Depth <= 1 m bgl
Depth <= 5 m bgl
0
5
10
20
Kilometers
N
W
E
S


N
W
E
S
Depth to shallow groundwater (m agl)
CPWES no dam dry
1 March 1970
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Depth <= 1 m bgl
Depth <= 5 m bgl
0
5
10
20
Kilometers


N
W
E
S
Depth to shallow groundwater (m agl)
CPWES dry
1 March 1970
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Depth <= 1 m bgl
Depth <= 5 m bgl
0
5
10
20
Kilometers


N
W
E
S
Depth to shallow groundwater (m agl)
Status quo wet
1 October 1978
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Depth <= 1 m bgl
Depth <= 5 m bgl
0
5
10
20
Kilometers


N
W
E
S
Depth to shallow groundwater (m agl)
CSWES no dam wet
1 October 1978
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Depth <= 1 m bgl
Depth <= 5 m bgl
0
5
10
20
Kilometers


N
W
E
S
Depth to shallow groundwater (m agl)
CPWES wet
1 October 1978
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Depth <= 1 m bgl
Depth <= 5 m bgl
0
5
10
20
Kilometers