
APPENDIX A

SUPPORTING DATA FOR MONTHLY PUMPING RATES

Appendix A - Monthly Pumpage from Groundwater System

Month	Goulais	Steeltown	Central Basin	Shannon	Lorna	East Basin
January 2000	183,362	214,852	398,214	77,617	173,063	250,680
February 2000	200,450	200,875	401,325	105,028	175,463	280,491
March 2000	223,232	215,278	438,510	76,688	169,076	245,764
April 2000	215,276	208,050	423,326	44,855	154,876	199,731
May 2000	224,980	215,351	440,331	106,780	129,722	236,502
June 2000	202,395	207,706	410,101	38,738	168,219	206,957
July 2000	210,514	215,202	425,716	145,826	166,393	312,219
August 2000	221,234	197,185	418,419	111,856	168,915	280,771
September 2000	225,131	161,920	387,051	31,548	140,061	171,609
October 2000	202,001	157,258	359,259	42,621	166,017	208,638
November 2000	163,961	198,729	362,690	42,942	130,797	173,739
December 2000	172,095	196,028	368,123	82,634	110,494	193,128
January 2001	170,421	205,004	375,425	53,628	155,240	208,868
February 2001	150,459	183,421	333,880	58,380	134,193	192,573
March 2001	149,712	206,266	355,978	69,340	153,572	222,912
April 2001	112,938	196,932	309,870	162,511	178,445	340,956
May 2001	128,844	202,794	331,638	106,482	202,719	309,201
June 2001	125,184	185,053	310,237	160,081	181,472	341,553
July 2001	204,810	193,309	398,119	112,278	203,855	316,133
August 2001	203,771	200,369	404,140	151,169	191,468	342,637
September 2001	197,662	188,604	386,266	93,404	119,145	212,549
October 2001	202,046	206,856	408,902	84,092	76,326	160,418
November 2001	202,411	199,949	402,360	88,968	34,668	123,636
December 2001	209,778	204,194	413,972	70,207	133,994	204,201
January 2002	202,380	206,248	408,628	47,883	119,911	167,794
February 2002	182,542	183,283	365,825	43,215	104,595	147,810
March 2002	190,369	180,470	370,839	79,311	141,473	220,784
April 2002	154,986	161,226	316,212	135,441	148,052	283,493
May 2002	160,480	202,617	363,097	130,600	153,500	284,100
June 2002	154,008	203,076	357,084	135,718	146,734	282,452
July 2002	155,484	209,016	364,500	139,010	153,649	292,659
August 2002	158,532	209,919	368,451	136,171	152,018	288,189
September 2002	152,857	173,178	326,035	131,633	150,007	281,640
October 2002	155,710	190,507	346,217	145,450	153,484	298,934
November 2002	39,024	182,723	221,747	145,317	149,143	294,460
December 2002	9,696	191,709	201,405	148,181	154,977	303,158
January 2003	-	192,418	192,418	150,844	158,035	308,879
February 2003	-	173,777	173,777	133,468	88,487	221,955
March 2003	45,980	192,474	238,454	47,238	22,700	69,938
April 2003	146,546	15,161	161,707	32	143,828	143,860
May 2003	154,808	152,646	307,454	41,466	141,366	182,832
June 2003	149,376	187,110	336,486	134,901	139,535	274,436
July 2003	153,325	176,078	329,403	137,241	117,373	254,614
August 2003	143,144	159,617	302,761	125,102	103,277	228,379
September 2003	149,282	176,859	326,141	76,064	127,250	203,314
October 2003	154,125	184,573	338,698	59,208	115,668	174,876
November 2003	145,692	171,217	316,909	85,872	72,345	158,217
December 2003	153,793	168,657	322,450	143,835	105,252	249,087
January 2004	155,406	186,488	341,894	134,121	118,624	252,745
February 2004	144,759	168,750	313,509	130,012	39,508	169,520

Appendix A - Monthly Pumpage from Groundwater System

Month	Goulais	Steelton	Central Basin	Shannon	Lorna	East Basin
March 2004	155,417	186,504	341,921	134,062	-	134,062
April 2004	149,823	177,478	327,301	139,807	-	139,807
May 2004	154,467	187,549	342,016	155,472	-	155,472
June 2004	149,416	180,328	329,744	149,132	-	149,132
July 2004	143,237	180,318	323,555	144,283	2,395	146,678
August 2004	136,882	161,028	297,910	132,837	95,252	228,089
September 2004	150,169	183,038	333,207	109,488	126,436	235,924
October 2004	156,869	188,266	345,135	130,290	120,109	250,399
November 2004	139,564	182,069	321,633	140,760	106,137	246,897
December 2004	158,478	187,453	345,931	163,914	126,004	289,918
January 2005	158,424	189,132	347,556	104,231	120,707	224,938
February 2005	142,677	156,368	299,045	-	133,082	133,082
March 2005	157,640	180,395	338,035	-	144,706	144,706
April 2005	153,901	180,807	334,708	92,525	106,213	198,738
May 2005	158,176	186,977	345,153	161,065	65,381	226,446
June 2005	153,165	175,837	329,002	138,632	123,756	262,388
July 2005	159,557	184,361	343,918	96,007	116,490	212,497
August 2005	159,219	194,920	354,139	103,483	113,386	216,869
September 2005	152,953	185,278	338,231	147,115	84,915	232,030
October 2005	160,418	200,050	360,468	95,597	97,214	192,811
November 2005	154,768	183,444	338,212	59,497	99,906	159,403
December 2005	162,480	201,580	364,060	-	119,994	119,994
January 2006	145,897	201,974	347,871	-	168,438	168,438
February 2006	142,660	182,306	324,966	-	156,026	156,026
March 2006	164,791	201,843	366,634	-	169,975	169,975
April 2006	159,065	182,681	341,746	-	157,656	157,656
May 2006	164,566	198,389	362,955	-	145,566	145,566
June 2006	159,251	193,412	352,663	-	130,123	130,123
July 2006	169,813	214,995	384,808	100,806	186,525	287,331
August 2006	172,801	220,767	393,568	93,887	165,133	259,020
September 2006	165,747	186,353	352,100	145,785	164,959	310,744
October 2006	169,991	142,169	312,160	151,702	165,830	317,532
November 2006	140,133	149,267	289,400	125,842	132,801	258,643

APPENDIX B

**EVALUATION OF WATER BUDGET ANALYSES AND TIER 1 STRESS ASSESSMENTS
BY S.S. PAPADOPULOS & ASSOCIATES INC. DECEMBER 2007**

**Sault Ste. Marie Region Conservation
Authority:**

**Evaluation of Water Budget Analyses
and Tier 1 Stress Assessments**

Prepared For:

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December 12, 2007

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Section 1

Introduction

MacViro and Kresin Engineering developed a conceptual understanding of the study area and developed the water budget analyses and stress assessment. The conclusion from the stress assessment is an indication that groundwater basins in SSMRCA have the potential to be significantly stressed. Mr. Frank Breen, P.G., has raised concerns regarding the adequacy of these analyses. In his draft peer review report, Mr. Breen indicated the overall conclusion regarding the stress assessment “needs to be critically evaluated since there is a great deal of information to the contrary”. A groundwater model of a portion of the study areas was developed for the Sault Ste. Marie Area Groundwater Management and Protection Study (R.J. Burnside & Associates Limited, 2003). In his detailed comments, Mr. Breen indicated, “Serious consideration should be made for utilizing the Burnside model in the Tier 1 analysis.”

MacViro Consultants (Genivar Ontario Inc.) has retained S.S. Papadopoulos & Associates, Inc. (SSP&A) to assess Mr. Breen’s recommendations regarding the Burnside (2003) model. In particular, SSP&A has been asked to evaluate whether a Tier 1 Stress Assessment conducted with the existing groundwater model would yield significantly different conclusions with respect to the potential stress level. In this assessment, SSP&A has reviewed the water budget calculations and Tier 1 Stress Assessment conducted by MacViro and Kresin Consultants, and developed alternative water budget analyses and Tier 1 Stress Assessments with the Burnside (2003) model. As part of the model applications we have reviewed detailed aspects of the modelling and we revisit the preliminary review comments on the model that we prepared in February 2005 (SSP&A, 2005).

The primary documents we have examined in preparing this report are:

- R.J. Burnside & Associates Limited, 2003: Sault Ste. Marie Area Groundwater Management and Protection Study, prepared for the City of Sault Ste. Marie PUC Services, June 2003;
- MacViro Consultants and Kresin Engineering, 2006: SSMRCA Water Budget Study: Water Budget Conceptual Understanding, prepared for the Sault Ste. Marie Region Conservation Authority, November 7, 2006;
- MacViro Consultants and Kresin Engineering, 2007: Sault Ste. Marie Region Conservation Authority Tier 1 Water Budget and Risk Assessment, prepared for the Sault Ste. Marie Region Conservation Authority, draft, May 14, 2007; and
- Breen, F., P.G., 2007: Comments Draft Tier 1 Report, Draft Technical Memorandum, prepared for the Sault Ste. Marie Region Conservation Authority, May 14, 2007.

Section 2

MacViro water budget analyses and Tier 1 Stress Assessment

In this section we review the fundamental aspects of the water budget analyses and Tier 1 Stress Assessments developed (MacViro and Kresin Engineering, 2007).

The locations of the groundwater basins in the SSMRCA study area are shown in Figure 2.1. In our review, we have focused on the water budgets for the Central and East basins. There are no significant withdrawals of water in the West Basin. The Goulais and Steelton wells are located in the Central basin, and the Shannon and Lorna wells are located in the East Basin. The Sault Ste. Marie Public Utilities Commission operates these wells.

MacViro and Kresin Engineering develop water balances following the approach presented in the Ontario Ministry of the Environment Clean Water Act Guidance Modules (Module 7: Draft Water Budget and Water Quantity Risk Assessment, October 2006, p. 92). The SSMRCA is subdivided into 32 subwatersheds, and a lumped water budget is developed for each subwatershed. The Tier 1 Stress Assessment developed by MacViro and Kresin Engineering are conducted on the scale of the groundwater basins delineated in Burnside (2003). Water budgets for the basins are assembled by accumulating flow terms for the subwatersheds that lie within their limits. This approach is appropriate because pumping is restricted to a few subwatersheds in the study area.

2.1 Components of the water budget

A generic basin is shown schematically in Figure 2.2. The water budget for this basin can be written as:

$$\Delta S = \sum IN - \sum OUT \quad (1)$$

where:

ΔS represents the change in groundwater storage in the basin;

$\sum IN$ represents the cumulative inflows into the basin, and

$\sum OUT$ represents the cumulative outflows from the basin.

The components of the water budget are shown in Figure 2.2. Substituting for the individual components of the water budget in Equation (1) yields:

$$\Delta S = [SW_{in} + GW_{in} + P] - [SW_{out} + GW_{out} + ET + Q_{out}] \quad (2)$$

The components of the water budget in Equation (2) are:

- SW_{in} and SW_{out} : surface water inflows and outflows from the basin, respectively;
- GW_{in} and GW_{out} : groundwater inflows and outflows from the basin, respectively;
- P : average precipitation;
- ET : average evaporation and plant transpiration; and
- Q_{out} : cumulative consumptive water use in the basin.

If we consider time-averaged conditions, and assume that the basin is in a state of long-term equilibrium, the change in storage is zero and Equation (2) reduces to:

$$SW_{in} + GW_{in} + P = SW_{out} + GW_{out} + ET + Q_{out} \quad (3)$$

Equation (3) represents a water budget for a geographical area *as a whole*. It is also possible to consider specific components of the hydrologic cycle by developing a water budget that accounts for the distribution of precipitation over an area, for example. Precipitation that falls over an area is allocated according to:

$$P = ET + RO + I \quad (4)$$

where RO denotes runoff and I denotes infiltration.

In the MacViro and Kresin Engineering water budget analyses, estimates of precipitation, evapotranspiration, runoff and infiltration are developed for each subwatershed (MacViro and Kresin Engineering, 2007; Table 3.2 and Appendix A). It is important to note here that this approach is not separate from, or in opposition to, the development of a distributed groundwater model. The estimation of infiltration in Equation (4) is an essential step in constraining the distribution of recharge that is assumed in a groundwater model.

2.2 Inflow from upland areas

At the scale of the basins, the significant inflows are:

- Inflow from upland areas; and
- Recharge to the water table from the infiltration of precipitation.

The basins are located at the base of Precambrian uplands. Inflows from the upland areas are considered by both MacViro and Kresin Engineering (2007) and in Burnside (2003) to represent significant fractions of the total flow into each basin. Referring to Table 3.2 in MacViro and Kresin Engineering (2007), the average annual precipitation (P) over the upland areas is about 1,000 mm and the average evapotranspiration (ET) is about 540 mm. The surplus, $P-ET$, is divided between runoff and infiltration. The estimated cumulative flows for the upland areas are tabulated below.

	Central basin ($\times 10^6$ m ³ /yr)	East basin ($\times 10^6$ m ³ /yr)
Cumulative upland runoff	6.9 (34% of P)	4.8 (32% of P)
Cumulative upland infiltration	2.6 (13% of P)	2.1 (14% of P)
Total	9.5 (46% of P)	6.9 (46% of P)

In our opinion, the results of the water budget calculations for the subwatersheds are reasonable; in particular, an estimate of infiltration that represents 13-14% over the upland areas is defensible. In light of the significance of the contribution from the upland areas, MacViro and Kresin Engineering adopt two methods: a method based on ‘summation of the infiltration in upgradient watersheds’, and an ‘equipotential method’. The close correspondence between the two essentially independent estimates of the upland infiltration provides some confidence in the results of the calculations.

In our review, we noted that the values of Q_R indicated in Figure 3.1 do not match those on Table 3.2 of MacViro and Kresin Engineering (2007). Furthermore, the values of Q_{in} indicated in Figure 3.2 do match those on Tables 3.3 and 3.4. The values of Q_R indicated on Table 3.2 do match those on Table 3.8. We have confirmed with MacViro that the values in Figure 3.1 are incorrect. The values were transcribed from the results of previous analyses and will be corrected.

Although the estimates of the upland infiltration are consistent, a key conceptual question with respect to the stress assessments for the basins remains, *How should the upland flow contribution be treated with respect to the downgradient basins?* The two ends of the spectrum of possibilities are:

- All of the upland runoff and infiltration is conveyed to the basins as stream flow that discharges at the edge of the upland area that is in turn conveyed as surface water to St Marys River; or
- All of the upland runoff and infiltration is conveyed to the basins infiltrates to the groundwater system at the edge of the upland area.

The MacViro and Kresin Engineering (2007) analysis assumes a condition between these two ends:

- The upland runoff is assumed to be conveyed to the basins as stream flow that is in turn conveyed as surface water to St Marys River; and
- The cumulative upland infiltration is assumed to recharge the downgradient basins over a relatively narrow strip designated the Recharge Zone (MacViro and Kresin Engineering, 2006; Figure 2-2).

The upland runoff and the infiltration represent about 33% and 14% of the precipitation over the upland areas, respectively. Therefore, the assumptions regarding the amount of water that recharges the downgradient basin are significant. In our opinion, the water budget analyses cannot be definitive. Detailed streamflow records and hydrogeologic data for the Recharge Zone are required to support or refute the assumptions invoked in the MacViro and Kresin Engineering analyses.

2.3 Groundwater recharge over the basins

In their analyses, MacViro and Kresin Engineering assume that the groundwater recharge occurs only over the Recharge Zone. The Recharge Zone corresponds to an area between the Precambrian upland and the lowlands, over which sand and gravel deposits are identified in the Quaternary soil map. A dashed line in Figure 2.3 and 2.4 indicates the Recharge Zone for the Central and East basins. The direct recharge over this area is in effect supplemented by the cumulative infiltration that occurs over the upland areas.

It is assumed that the remaining portions of the basins are overlain with low permeability clay materials. Furthermore, it is indicated that the water-supply aquifer in the lowland areas is under artesian conditions. Although reliable water level data are not available to support the second observation, it is correct to note there will be no recharge to a confined aquifer in which the hydraulic gradient is upwards. The conception of the recharge is at least consistent with respect to the geologic description of the surficial materials.

2.4 Results of the water budget analyses and Tier 1 Stress Assessments

The results of the MacViro and Kresin Engineering water budget calculations for the Central and East basins are summarized on Tables 2.1 and 2.2, respectively. The components of the water budget are shown graphically for the Central and East basins in Figures 2.3 and 2.4, respectively. The columns on Tables 2.1 and 2.2 designated “Inflow from upland areas” represent the cumulative infiltration over the upland areas. The columns on Tables 2.1 and 2.2 designated “Total inflow” represent the sum of the cumulative infiltration over the upland areas and the direct recharge over the Recharge Zones. It is important to note that the reported flows are estimates, and the number of significant figures used on the tables is not consistent with their approximate nature. The values are reproduced verbatim from MacViro and Kresin Engineering (2007).

Tier 1 stress assessments are also included on Tables 2.1 and 2.2. The Tier 1 stress assessments are calculated following the MOE Guidance Document:

$$SA = \frac{Q_{OUT}}{\sum Q_{IN} - Q_{RESERVE}} \quad (5)$$

For Tier 1, the reserve flow is set at 10% of the cumulative inflow to each basin.

The stress assessment for the Central Basin for current groundwater withdrawals is 39%, and 42% for withdrawals projected 25 years into the future. The stress assessment for the East Basin for current groundwater withdrawals is 37%, and 41% for withdrawals projected 25 years into the future. Referring to Table 7 of MOE Guidance Module 7, the stress assessments for both basins fall in the “Significant” category with respect to long-term average conditions, $SA > 25\%$. The categories of the stress assessments do not change for the projected increases in groundwater withdrawals.

Table 2.1 Groundwater budget summary for the Central Basin

Recharge (m ³ /yr)		Inflow from upland areas (m ³ /yr)		Total inflow (m ³ /yr)	10% water reserve (m ³ /yr)	Adjusted groundwater supply (m ³ /yr)	Water use (m ³ /yr)		Stress assessment	
Subwatershed	Rate	Subwatershed	Rate				Current	+ 25 years	Current	+25 years
12	373 258	12	2 596 708	14 261 270	1 426 127	12 835 143	4 945 060	5 439 566	0.39	0.42
6	126 926	6	24 470							
18	392 401	18	3 120 907							
14	622 869	14	1 199 723							
7	69 549	15	1 362 948							
15	827 228	19	3 376 475							
19	63 841									
9	71 966									
11	32 002									
Total	2 580 040	Total	11 681 231							

Table 2.2 Groundwater budget summary for the East Basin

Rainfall recharge (m ³ /yr)		Inflow from upland areas (m ³ /yr)		Total inflow (m ³ /yr)	10% water reserve (m ³ /yr)	Adjusted groundwater supply (m ³ /yr)	Water use (m ³ /yr)		Stress assessment	
Subwatershed	Rate	Subwatershed	Rate				Current	+ 25 yrs	Current	+25 yrs
4	485433	13	530270	8 613 060	861 060	7 751 754	2 867 180	3 153 898	0.37	0.41
9	622140	21	1331625							
13	12289	19	502400							
16	761836	22	786600							
19	94944	23	2562000							
21	106123	24	817400							
Total	2 082 765	Total	6 530 295							

2.5 Alternative Tier 1 Stress Assessments for the basins

In our opinion, the Tier 1 Stress Assessment developed by MacViro and Kresin Engineering is conservative, in that it assumes a minimum contribution to the basins from precipitation over the upland areas. We have developed alternative stress assessments assuming a maximum contribution to the basins from upland areas. These stress assessments are calculated assuming that the total surplus, runoff plus infiltration, is conveyed to the municipal water-supply aquifers. The alternative stress assessment is presented on Tables 2.3 and 2.4. The columns on Tables 2.3 and 2.4 designated “Cumulative surplus over upland areas” represent the sum of the cumulative runoff and infiltration over the upland areas.

The alternative stress assessment for the Central Basin for current groundwater withdrawals is 17%, and 18% for withdrawals projected 25 years into the future. The stress assessment for the East Basin for current groundwater withdrawals is 13%, and 14% for withdrawals projected 25 years into the future. Referring to Table 7 of MOE Guidance Module 7, the stress assessments for both basins fall in the “Moderate” category with respect to long-term average conditions, $10\% < SA < 25\%$. The categories of the stress assessments do not change for the projected increases in groundwater withdrawals.

In our opinion, following the methodology adopted by MacViro and Kresin Engineering, the “true” stress assessments for the Central and East basin lies in the range of Moderate to Significant.

Table 2.3 Alternative groundwater budget summary for the Central Basin

Recharge (m ³ /yr)		Cumulative surplus over upland areas (m ³ /yr)		Total inflow (m ³ /yr)	10% water reserve (m ³ /yr)	Adjusted groundwater supply (m ³ /yr)	Water use (m ³ /yr)		Stress assessment	
Subwatershed	Rate	Subwatershed	Rate				Current	+ 25 years	Current	+25 years
12	373 258	12	5 405 600	32 776 840	3 277 684	29 499 156	4 945 060	5 439 566	0.168	0.184
6	126 926	6	93 200							
18	392 401	18	6 291 000							
14	622 869	14	4 566 800							
7	69 549	15	4 147 400							
15	827 228	19	9 692 800							
19	63 841									
9	71 966									
11	32 002									
Total	2 580 040	Total	30 196 800							

Table 2.4 Alternative groundwater budget summary for the East Basin

Rainfall recharge (m ³ /yr)		Cumulative surplus over upland areas (m ³ /yr)		Total inflow (m ³ /yr)	10% water reserve (m ³ /yr)	Adjusted groundwater supply (m ³ /yr)	Water use (m ³ /yr)		Stress	
Subwatershed	Rate	Subwatershed	Rate				Current	+ 25 years	Current	+25 years
4	485433	13	1 864 000	25 196 365	2 519 637	22 676 729	2 867 180	3 153 898	0.126	0.139
9	622140	21	5 452 200							
13	12289	19	1 491 200							
16	761836	22	2 656 200							
19	94944	23	8 527 800							
21	106123	24	3 122 200							
Total	2 082 765	Total	23 113 600							

Section 3

Water budget analyses and Tier 1 Stress Assessment with the groundwater model

SSP&A reviewed the Burnside (2003) groundwater model in their role as internal peer reviewers for the SSMRCA Tier 1 Stress Assessment (SSP&A, 2005). During their preliminary review, SSP&A raised several questions about the model that cast doubt on its reliability. At that time it was not possible to conduct a detailed evaluation of the model because the model files were not available. The model files have subsequently been made available, and in this section we revisit the groundwater modelling in the context of the Tier 1 stress assessment.

3.1 Overview of the groundwater model

Waterloo Numerical Modeling Corporation (WNMC) developed the groundwater model and documentation of the model is presented in Burnside (2003; Appendix G). WNMC developed the three-dimensional finite-difference model with the United States Geological Survey groundwater flow simulator MODFLOW, within the graphical user interface Visual MODFLOW. The limits of the groundwater model are shown in Figure 3.1. The model covers an area of approximately 130 km². As shown in Figure 3.1, the limits of the groundwater model roughly match the combined limits of the Central and East basins delineated by MacViro and Kresin Engineering.

The model includes 6 model layers with the main aquifers represented by model layers 4 and 5. Layer 4 represents the coarse sand and gravel material, and layer 5 represents the sandstone and the main aquifers.

The hydraulic conductivities of the model layers and the recharge rates were adjusted to match water levels from MOE water well records. It is important to note that the water levels in the MOE records are not data; in the sense that data refer to “facts”. Rather, the water level information has highly variable reliability. Although the water levels in the MOE records provide some generalized indications of groundwater levels; they are of highly variable reliability cannot be used to evaluate local conditions. The reliability and appropriate use of water levels from MOE records are discussed in a separate technical memorandum (SSP&A, 2007).

The calculated water levels and targets from the MOE water well records are shown in a scatterplot in Figure 3.2. The results shown in the figure indicate clearly the significant scatter in the MOE targets. The Root-Mean-Square (RMS) error is 10.7 m; in essence, this means that the typical error in water level at a particular location is of the order of ± 10.7 m.

The numerical groundwater model may in some sense be regarded as a water balance calculator. Although water balances are calculated at the level of the individual grid blocks, the results can also be used to develop water budgets at the basin scale. It is important to note that the water balance is developed from the water table down; therefore, recharge from the infiltration of precipitation is specified in the analysis rather than precipitation, runoff, evapotranspiration and infiltration. For a steady-state groundwater model the basin-scale water balance is written as:

$$GW_{in} + I + GW_{transboundary} + Q_{RIV} = GW_{out} + Q_{out} \quad (6)$$

where the only terms that have not been defined previously are:

$GW_{transboundary}$: net groundwater inflow to the basin from other basins; and
 I : infiltration of precipitation; that is, recharge to the water table.

As with the MacViro and Kresin Engineering analyses, the inflow from upland areas is a significant component of the water budget. In the MacViro and Kresin Engineering analyses an explicit term represents flow from the uplands. In contrast, the northern boundary of the groundwater model is impermeable and the flow from the uplands is represented as a zone of increased recharge along the northern boundary of the model.

The distribution of recharge is shown in Figure 3.3. The zone of elevated recharge along the boundary is assigned a recharge rate of 2,100 mm/yr. This rate is more than double the annual rainfall, and is clearly intended to account for inflows in excess of the infiltration of precipitation over this area.

The MacViro and Kresin Engineering conception of a Recharge Zone is also evident in Figure 3.3. The area of the groundwater model over which a recharge rate of 250 mm/yr is applied corresponds to the Recharge Zone shown in Figures 2.3 and 2.4. This rate is somewhat higher than the range of infiltration rates estimated in MacViro and Kresin Engineering, but of a similar order of magnitude.

Recharge rates of 60 mm/yr and 200 mm/yr are specified over the remaining portions of the model. These rates are relatively high considering that the surficial materials have been described as being clayey. It is also not clear to us how this recharge can be reconciled with the suggestion that there are artesian conditions in the municipal water-supply aquifer. If there are indeed artesian conditions at depth, the recharge applied over the basins could not supply the water-supply aquifer. In the next section, water budgets are developed with the model for the entire basins. If water budgets are developed for the water-supply aquifer itself it may be more appropriate to exclude the lowland recharge from the analyses.

3.2 Water budget analyses and Tier 1 Stress Assessments with the model

We have developed water budgets for the Central and East basins by extracting results from the groundwater model. The water budget analyses are summarized on Tables 3.1 and 3.2. The results of the water budget analyses are shown graphically for the Central and East basins in Figures 3.4 and 3.5, respectively.

As with the reported flows for the MacViro and Kresin Engineering water budget analyses, the number of significant figures used on Tables 3.1 and 3.2 is not consistent with the approximate nature of these flows. The results of the model calculations are precise, but generally not accurate. The values are reproduced verbatim from the Burnside (2003) groundwater model.

Tier 1 stress assessments are also included on Tables 3.1 and 3.2. The Tier 1 stress assessments are calculated following the MOE Guidance Document. For Tier 1, the reserve flow is set at 10% of the cumulative inflow to each basin. The only pumping included in the groundwater model are the withdrawals from the municipal supply wells in the Central and East basins. MacViro and Kresin Engineering include pumping in addition to the withdrawals from the municipal supply wells. We refer to these additional withdrawals as “other” pumping. We have developed two stress assessments for each basin:

- Excluding “other” pumping; and
- Including “other” pumping.

The stress assessment for the Central Basin considering only municipal withdrawals is 20%. The stress assessment for the Central Basin including other pumping is 24%. Referring to MOE Guidance Module 7 Table 7, the stress assessments for both basins fall in the “Moderate” category with respect to long-term average conditions, $10\% < SA < 25\%$. The corresponding stress assessments for the East Basin are 29% and 30%. These stress assessments fall in the “Significant” category with respect to long-term average conditions, $SA > 25\%$. The categories of the stress assessments are the same with or without the non-municipal groundwater withdrawals.

Table 3.1 Risk assessments for the Central Basin, Assumed pumping

Groundwater inflow	
	Volume (m ³ /yr)
Cumulative recharge at a rate of 2100 mm/yr	17 634 609
Cumulative recharge at rates of 250 mm/yr, 200 mm/yr and 60 mm/yr	6 473 641
Total	24 108 250
Adjusted inflow (90 % of cumulative inflow)	
	21 697 425
Assumed withdrawals	
	Volume (m ³ /yr)
Municipal water supply (Goulais, Steelton)	4 380 000
Others	804 428
Total	5 184 428
Stress assessment	
Excluding “other” pumping	20.2%
Including “other” pumping	23.9%

Table 3.2 Risk assessments for the East Basin, Assumed pumping

Groundwater inflow	
	Volume (m ³ /yr)
Cumulative recharge at a rate of 2100 mm/yr	9 208 059
Cumulative recharge at rates of 250 mm/yr, 200 mm/yr and 60 mm/yr	7 613 170
Total	16 821 229
Adjusted inflow (90 % of cumulative inflow)	
	15 139 106
Assumed withdrawals	
	Volume (m ³ /yr)
Municipal water supply (Shannon, Lorna)	4 380 000
Others	192 364
Total	4 572 364
Stress assessment	
Excluding “other” pumping	28.9%
Including “other” pumping	30.2%

3.3 Consideration of actual pumping rates

The groundwater model incorporates a simplified assignment of municipal pumping. Each of the four municipal wells is assigned a constant pumping rate of 6,000 m³/d. The assumed and actual pumping rates are tabulated below. The actual long-term average pumping rates are estimated from MacViro and Kresin Engineering (2007; Figures 4.3 and 4.4). The pumping rates assumed for the Central Basin are relatively close to the actual pumping rates. However, the assumed pumping for the East Basin is about 65% higher than observed.

Wells	Pumping rate in the model (m ³ /d)	Actual average pumping rate (m ³ /d)
Central Basin		
Goulais	6 000	5 150
Steelton	6 000	6 100
Total	12 000	11 250
East Basin	6 000	3 150
Shannon	6 000	4 150
Lorna	12 000	7 300

We have used the existing groundwater model to simulate steady groundwater flow using the actual pumping rates. The calculated and target water levels are plotted in Figure 3.6. For the assumed pumping rates, the mean residual (that is, the average difference between the calculated and target levels at a particular location) is -2.0 m. For the actual pumping rates, the mean residual is -1.4 m. There is a slight improvement in the results, but the RMS error of 10.6 m is not significantly different. The similarity between the model results is illustrated in Figure 3.7, which shows cumulative probability distributions of the model residuals for both sets of pumping rates. The results are essentially indistinguishable. The implications of the results obtained with actual pumping rates are significant. The results demonstrate that the available water level targets are not sufficient to support distinguishing between significantly different pumping rates in the East Basin.

For completeness, we have developed water budgets and Tier 1 stress assessments with the groundwater model using the actual pumping rates. The results of the analyses are summarized on Tables 3.3 and 3.4. The results of the water budget analyses with the actual pumping rates are shown graphically for the Central and East basins in Figures 3.8 and 3.9, respectively.

The stress assessment for the Central Basin considering only municipal withdrawals is 19%. The stress assessment for the Central Basin including other pumping is 23%. The corresponding stress assessments for the East Basin are 18% and 19%. Referring to MOE Guidance Module 7 Table 7, the stress assessments for both basins fall in the “Moderate” category with respect to long-term average conditions, $10\% < SA < 25\%$. The categories of the stress assessments are the same with or without the non-municipal groundwater withdrawals.

Table 3.3 Risk assessments for the Central Basin, Actual pumping

Groundwater inflow	
	Volume (m ³ /yr)
Cumulative recharge at a rate of 2100 mm/yr	17 634 609
Cumulative recharge at rates of 250 mm/yr, 200 mm/yr and 60 mm/yr	6 473 641
Total	24 108 250
Adjusted inflow (90 % of cumulative inflow)	
	21 697 425
Actual withdrawals	
	Volume (m ³ /yr)
Municipal water supply (Goulais, Steelton)	4 127 000
Others	804 428
Total	4 931 428
Stress assessment	
Excluding “other” pumping	19.0%
Including “other” pumping	22.7%

Table 3.4 Risk assessments for the East Basin, Actual pumping

Groundwater inflow	
	Volume (m ³ /yr)
Cumulative recharge at a rate of 2100 mm/yr	9 208 059
Cumulative recharge at rates of 250 mm/yr, 200 mm/yr and 60 mm/yr	7 613 170
Total	16 821 229
Adjusted inflow (90 % of cumulative inflow)	
	15 139 106
Actual withdrawals	
	Volume (m ³ /yr)
Municipal water supply (Shannon, Lorna)	2 668 000
Others	192 364
Total	2 860 364
Stress assessment	
Excluding “other” pumping	17.6%
Including “other” pumping	18.9%

3.4 Reconciliation of the water budget analyses

In theory it should be possible to reconcile the water budget analyses developed by MacViro and Kresin Engineering and the analyses developed from the Burnside (2003) analyses. However, it is important to note that there are fundamental differences between the water budget analyses. In particular, the analyses differ considerably in their treatment of the contributions from the upland areas and in recharge over the groundwater basins. The quantitative differences are summarized on the tables below. The differences are sufficient to account for the differing stress assessments of “Significant” and “Moderate”.

The analyses developed by MacViro and Kresin Engineering and the groundwater model should be complementary. In our opinion, data are not available to reconcile the differences between the analyses and to support the development of a “consensus” analysis.

MacViro and Kresin Engineering analysis ($\times 10^6$ m ³ /yr)		
	Central Basin	East Basin
Inflow from uplands	11.7	6.5
Inflow over the Recharge Zone	2.6	2.1
Recharge over lowlands	0.0	0.0
Total inflow	14.3	8.6
Actual pumping	4.9	2.9

Burnside (2003) groundwater model ($\times 10^6$ m ³ /yr)		
	Central Basin	East Basin
Inflow from uplands + Inflow over the Recharge Zone	17.6	9.2
Recharge over lowlands	6.5	7.6
Total inflow	24.1	16.8
Assumed pumping	4.4	4.4

Section 4

Conclusions and recommendations

We have reviewed the water budget calculations and Tier 1 Stress Assessment conducted by MacViro and Kresin Consultants, and developed alternative water budget analyses and Tier 1 Stress Assessments with the Burnside (2003) model. The objective of the review has been to evaluate whether a Tier 1 Stress Assessment conducted with the existing groundwater model yields significantly different conclusions with respect to the potential stress level. The main findings of our review of the water budget analyses are listed below.

1. Water budgets and Tier 1 Stress Assessment have been developed for the SSMRCA on the scale of the groundwater basins delineated in Burnside (2003). This approach is appropriate because pumping is restricted to a few subwatersheds in the study area.
2. We have reproduced the MacViro and Kresin Engineering Tier 1 stress assessment for the Central and East basins. For current groundwater withdrawals the stress assessments are:
 - Central Basin: 39%; and
 - East Basin: 37%,

The stress assessments for both basins fall in the “Significant” category with respect to long-term average conditions, $SA > 25\%$. The stress assessments are not significantly different for withdrawals projected 25 years into the future.

3. We have developed alternative stress assessments assuming likely maximum contributions to the basins from upland areas. For current groundwater withdrawals the stress assessments are:
 - Central Basin: 17%; and
 - East Basin: 13%,

The stress assessments for both basins fall in the “Moderate” category with respect to long-term average conditions, $10\% < SA < 25\%$. The stress assessments are not significantly different for withdrawals projected 25 years into the future.

4. In our opinion, following the methodology adopted by MacViro and Kresin Engineering, the “true” stress assessments for the Central and East basis lies in the range of Moderate to Significant.

5. We have applied the existing Burnside (2003) groundwater model to develop alternative water budget analyses and stress assessments. For assumed groundwater withdrawals the stress assessments are:

- Central Basin: 20%; and
- East Basin: 29%,

The stress assessment for the Central Basin falls in the “Moderate” category. The stress assessment for the East Basin falls in the “Significant” category. The stress assessments do not change if non-municipal groundwater withdrawals are included in the analyses.

6. We have developed alternative water budget analyses and stress assessments with the model, using actual average pumping rates. The stress assessments are:

- Central Basin: 19%; and
- East Basin: 18%,

The stress assessments for both basins fall in the “Moderate” category. The stress assessments do not change if non-municipal groundwater withdrawals are included in the analyses.

7. The flows quantities in the water budgets developed by MacViro and Kresin Engineering are significantly different from the corresponding quantities in the groundwater flow model. These differences reflect fundamental differences in the way upland flows are considered in the analyses and the treatment of recharge over the lowland areas. These differences affect the outcomes of the Tier 1 stress assessment.

The assumptions regarding upland recharge are discussed in detail in our report. The significance of the assumptions regarding lowland recharge is best appreciated by comparing the two tables on Page 17. In the groundwater model, for both basins the recharge over the lowlands exceeds the municipal pumping. It is possible to develop new stress assessments by adding the lowland recharge to the MacViro and Kresin Engineering analysis. However, in our opinion it is more realistic to remove this recharge from the groundwater model. With respect to the stress assessments, adding the lowland recharge to the MacViro and Kresin Engineering analysis might change a "Significant" assessment to a "Moderate" assessment, or removing lowland recharge from the groundwater model might change a "Moderate" assessment to a "Significant" assessment. It is possible to simulate groundwater flow with reduced recharge; however, we anticipate that just as with the pumping rates, the "calibration" would not be able to detect the change.

8. In general, we support the application of groundwater models to assist in developing water budget analyses. However, for this application of models it is essential that these models be appropriately calibrated with reliable data. Models are valuable tools, but they can never replace the collection and critical interpretation of site-specific data.
9. The only way to resolve the differences between the water budget analyses is to collect and interpret data from stream gauges and dedicated groundwater monitoring wells. However, in spite of the differences, the conclusions from the analyses are generally consistent; the Tier 1 stress assessments for the Central and East basins are in the range of “Moderate” to “Significant.” In our opinion, these stress assessments are appropriate. In our experience, we have found that at assessments that are at least “Moderate” are developed for municipal groundwater takings.

Section 5

References

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- S.S. Papadopoulos & Associates, Inc., 2007: Use of MOE Water Well Records in regional groundwater flow studies, memorandum prepared by C.J. Neville for the Ontario Ministry of Natural Resources, March 7, 2007.

FIGURES

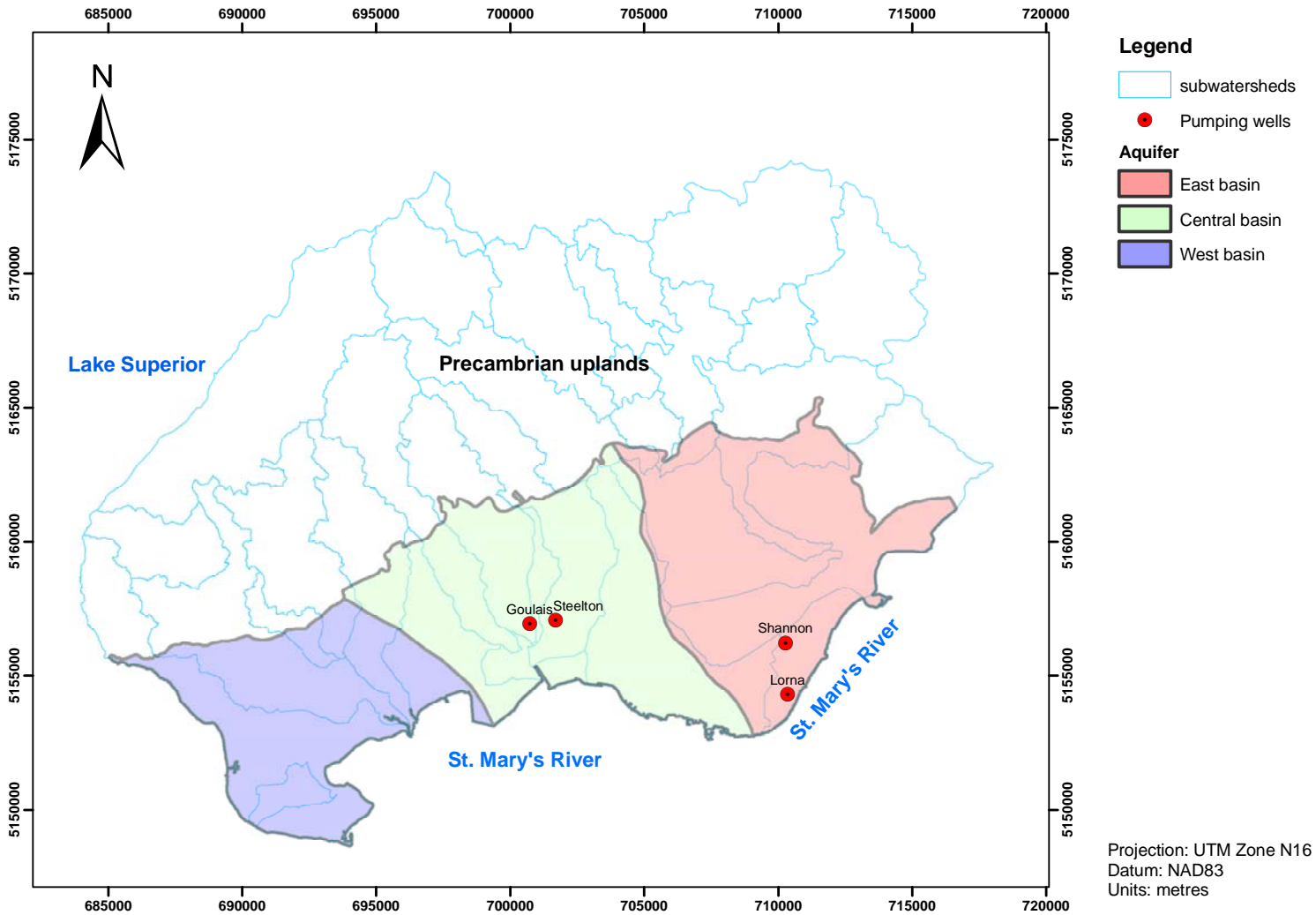


Figure 2.1 Groundwater basins for the Tier 1 Stress Assessment

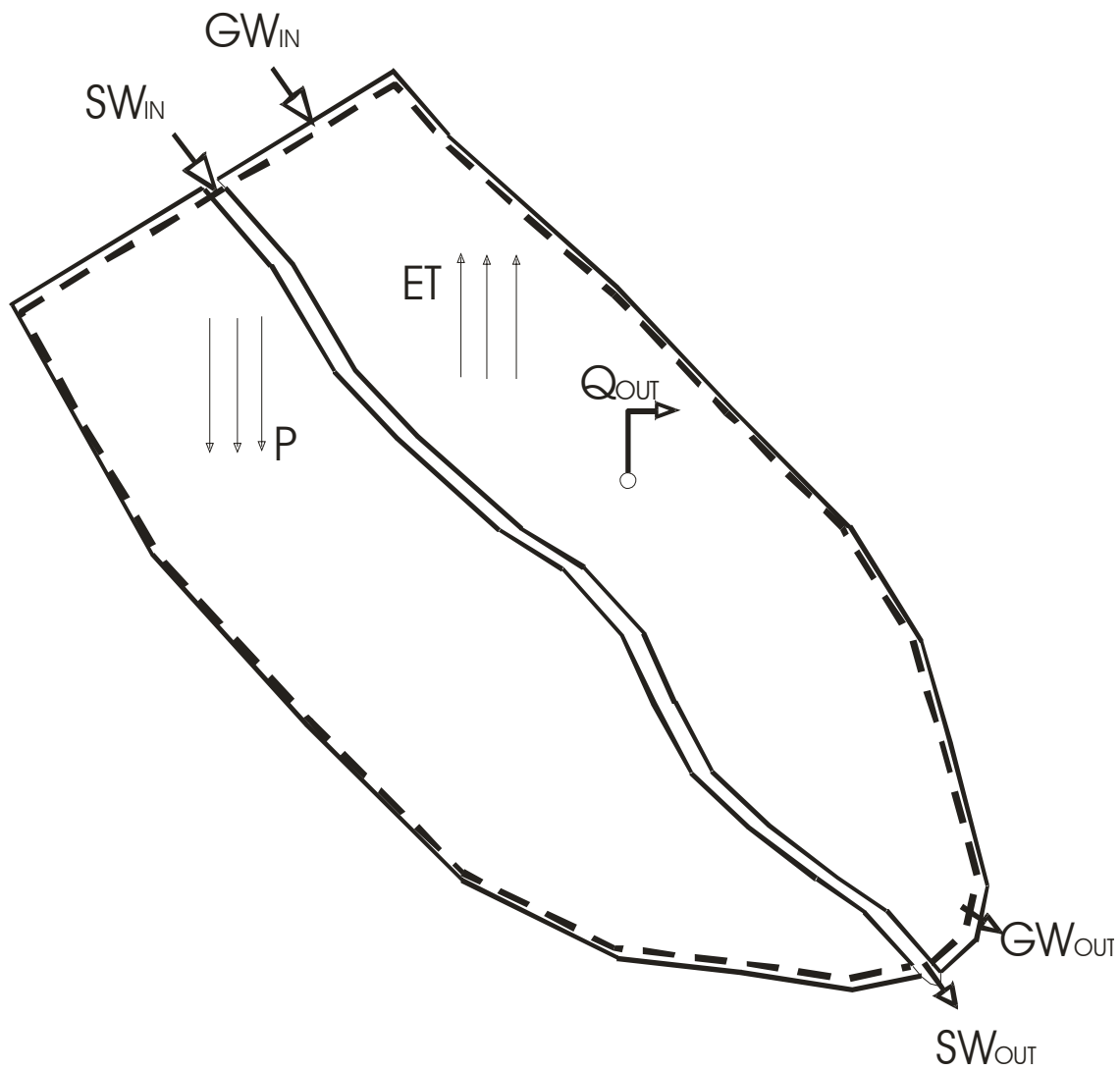


Figure 2.2 Components of the water budget for a groundwater basin

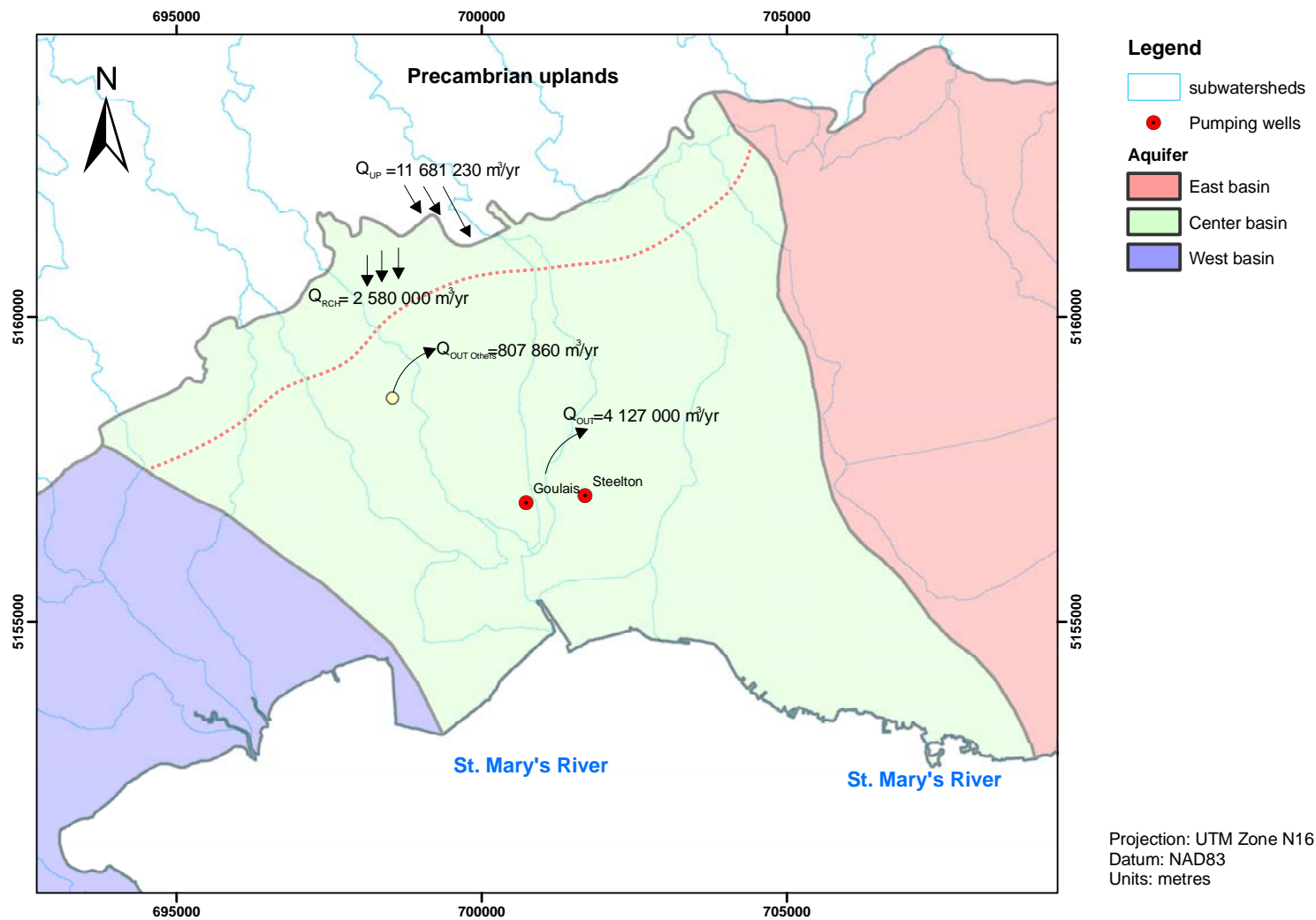


Figure 2.3 Water budget components for Tier 1 Stress Assessment, Central Basin

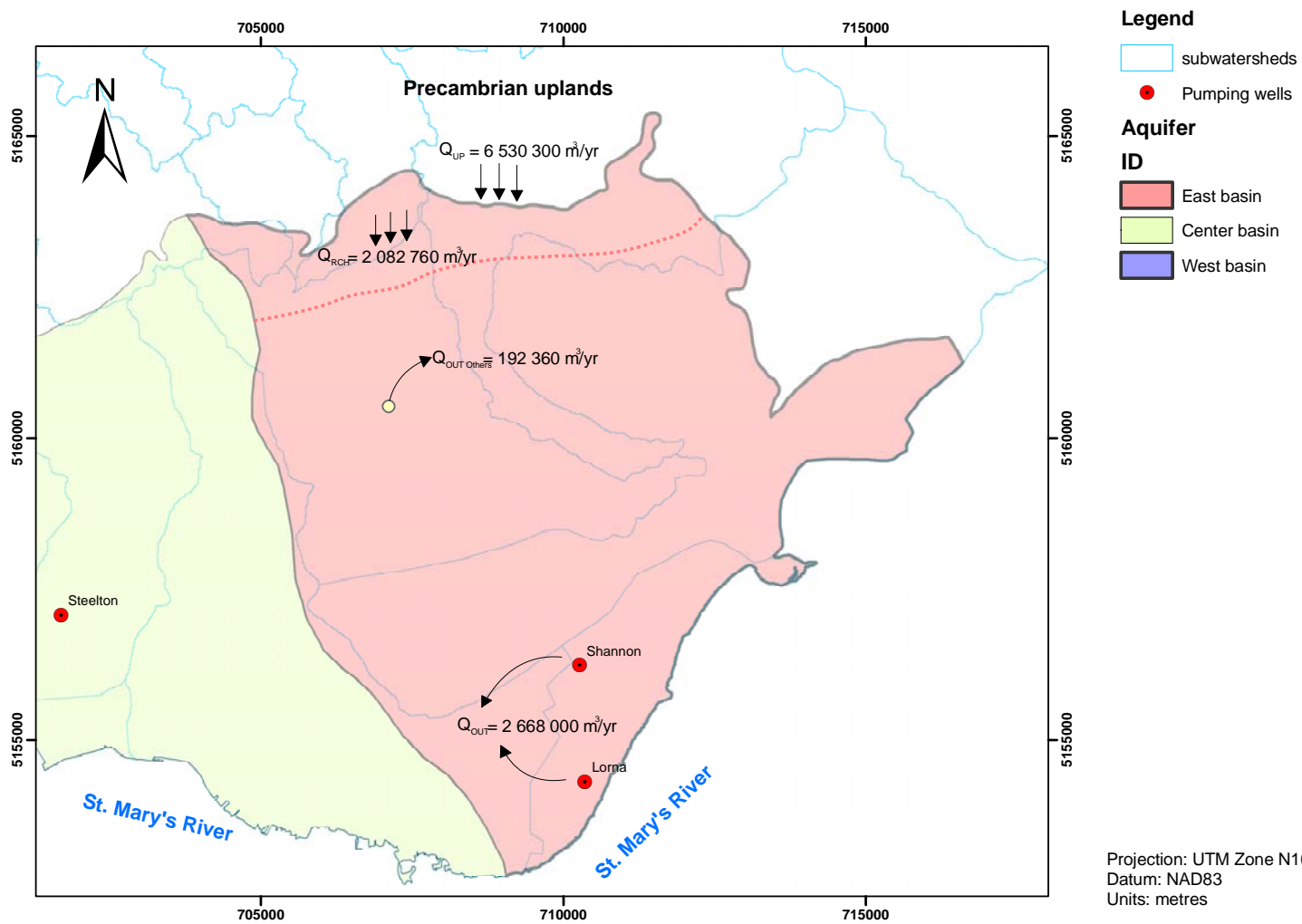


Figure 2.4 Water budget components for Tier 1 Stress Assessment, East Basin

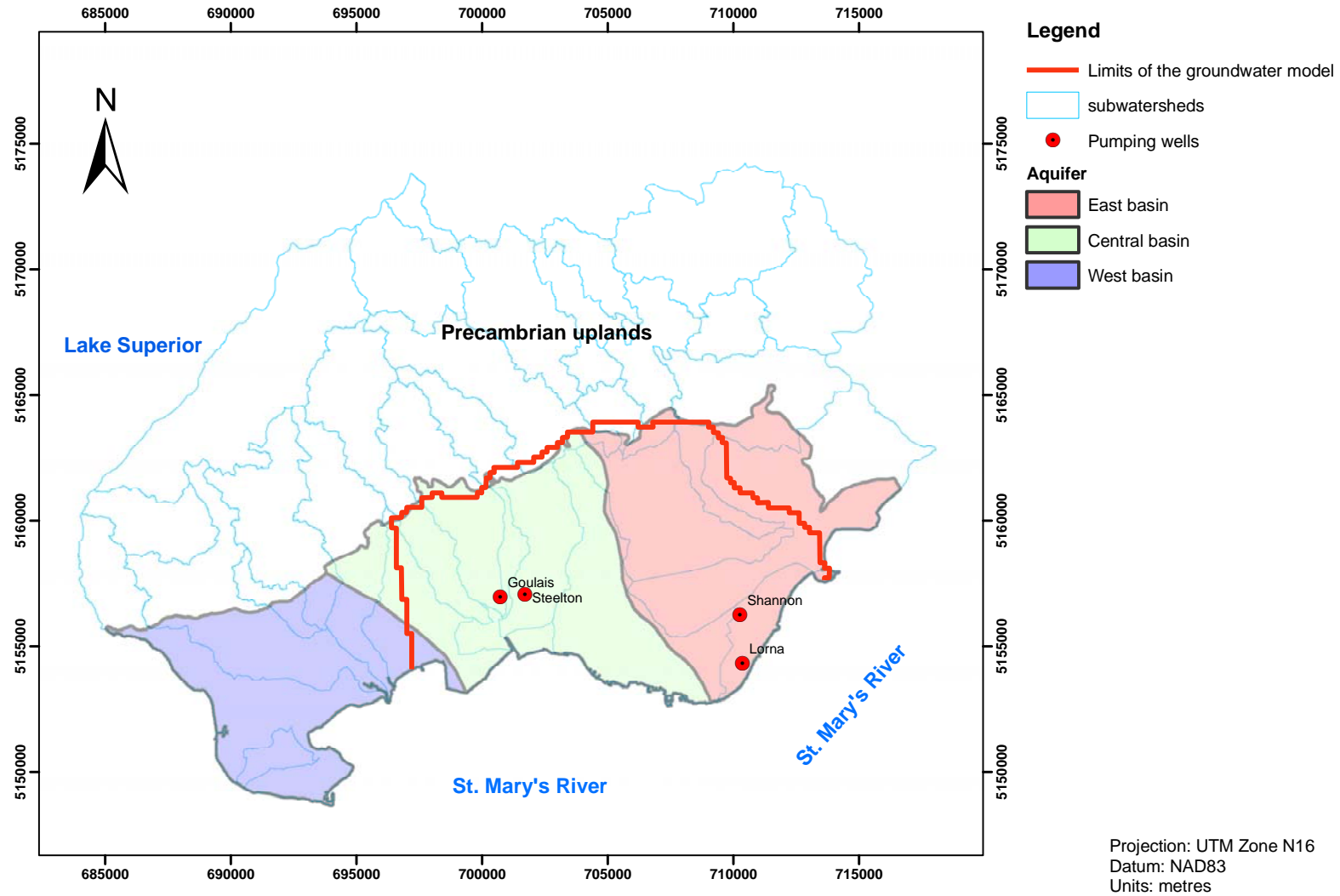
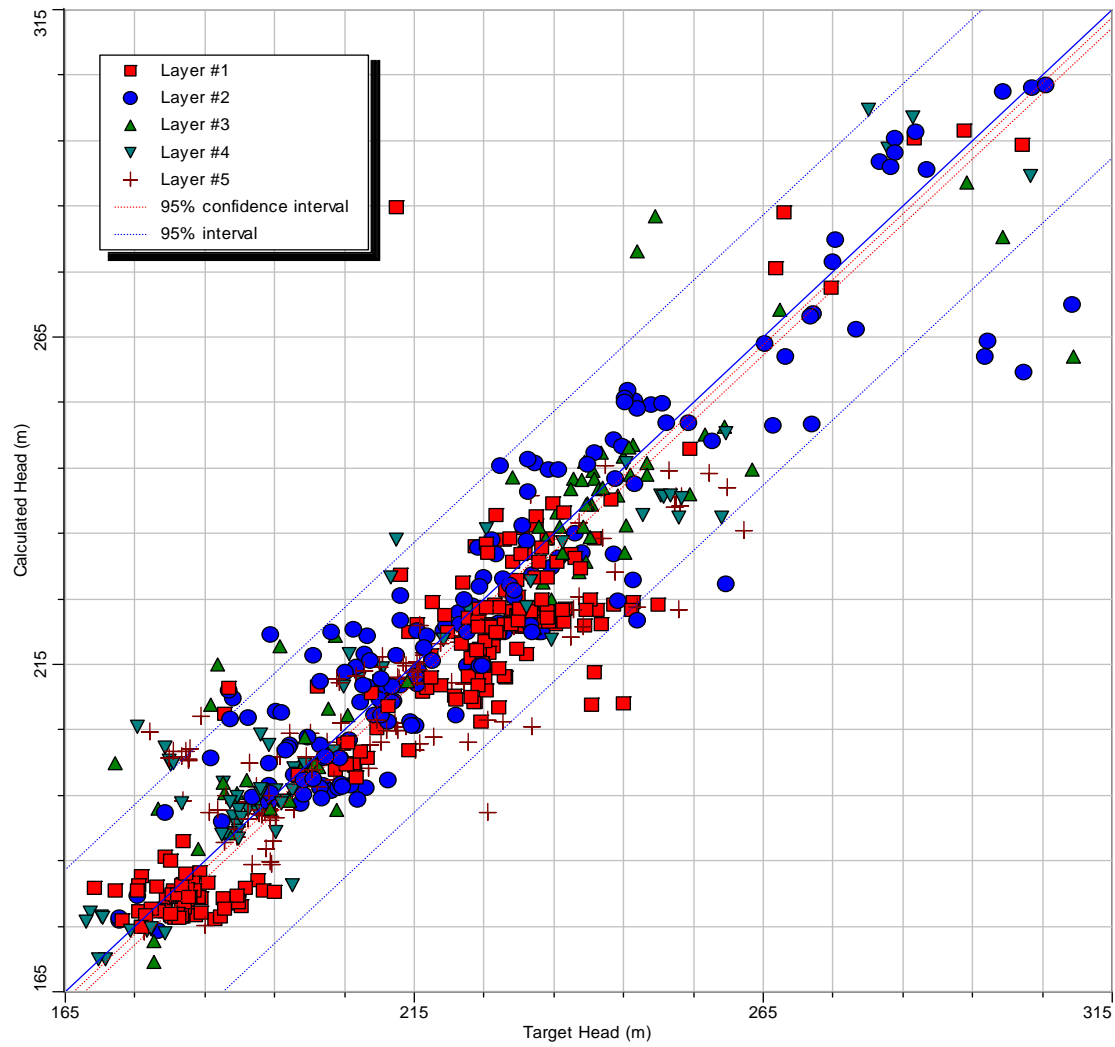


Figure 3.1 Limits of the Burnside (2003) groundwater model



Num. of Data Points : 686
 Max. Residual: 72.377 (m) at 1333/1333
 Min. Residual: -0.027 (m) at 1418/1418
 Residual Mean : -1.99 (m)
 Abs. Residual Mean : 7.694 (m)

Standard Error of the Estimate : 0.401 (m)
 Root Mean Squared : 10.691 (m)
 Normalized RMS : 7.554 (%)
 Correlation Coefficient : 0.924

Figure 3.2 Comparison of calculated and target water levels, original pumping rates

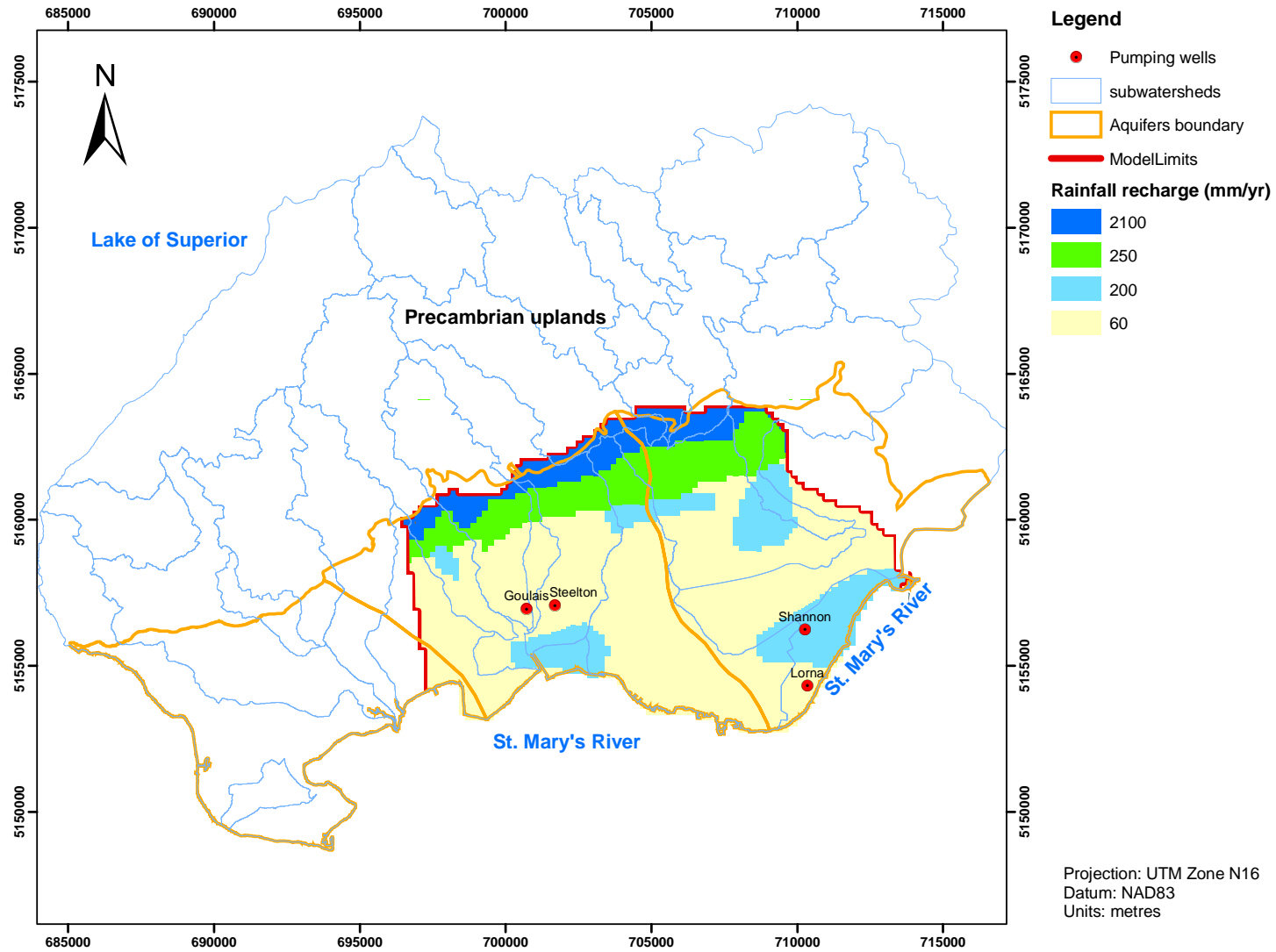


Figure 3.3 Distribution of recharge in the groundwater model

Water budget item	Rate (m ³ /yr)
GW _{IN}	17 634 609
Q _{RCH}	6 473 641
GW _{Transboundary}	-3 171 120
Q _{OUT}	-4 380 000
Q _{RIV}	10 624 351
GW _{OUT}	-27 181 287

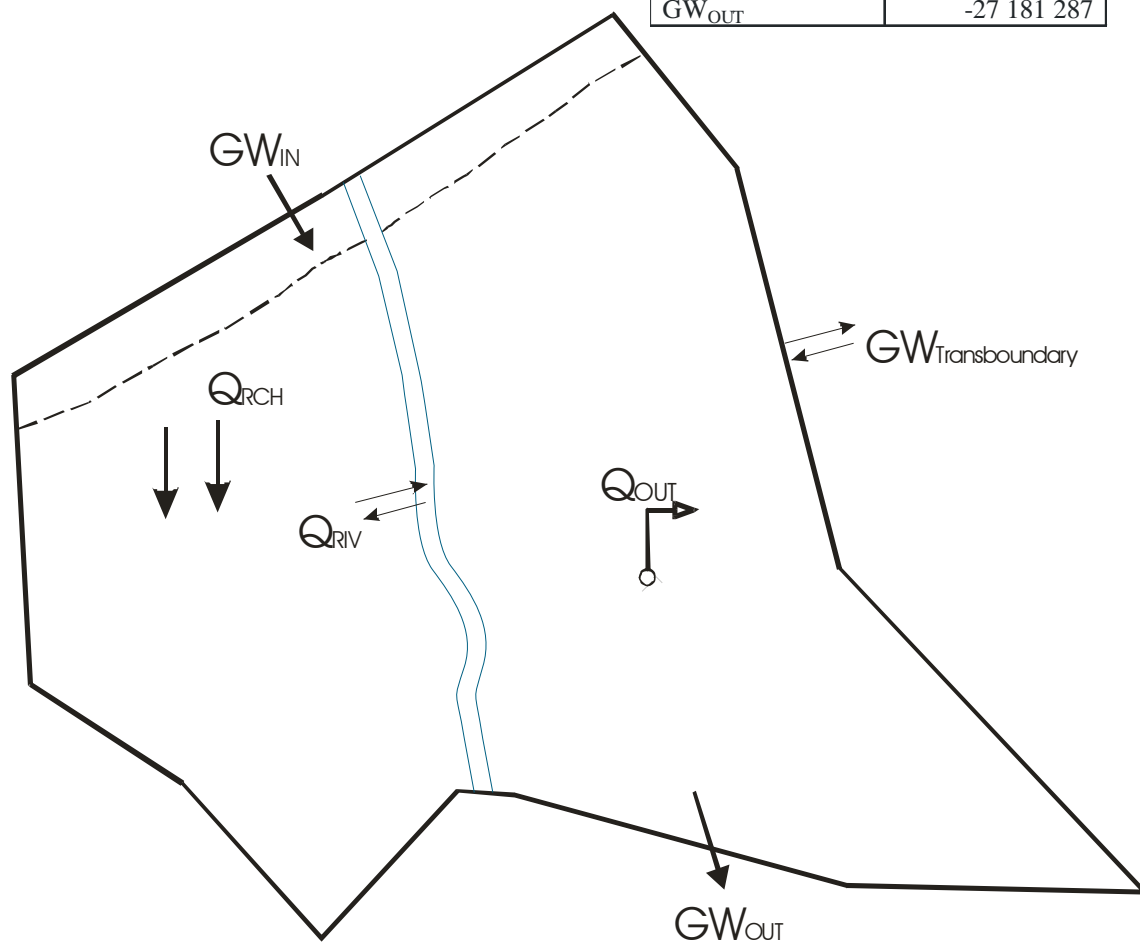


Figure 3.4 Groundwater budget for the Central Basin developed with the groundwater model

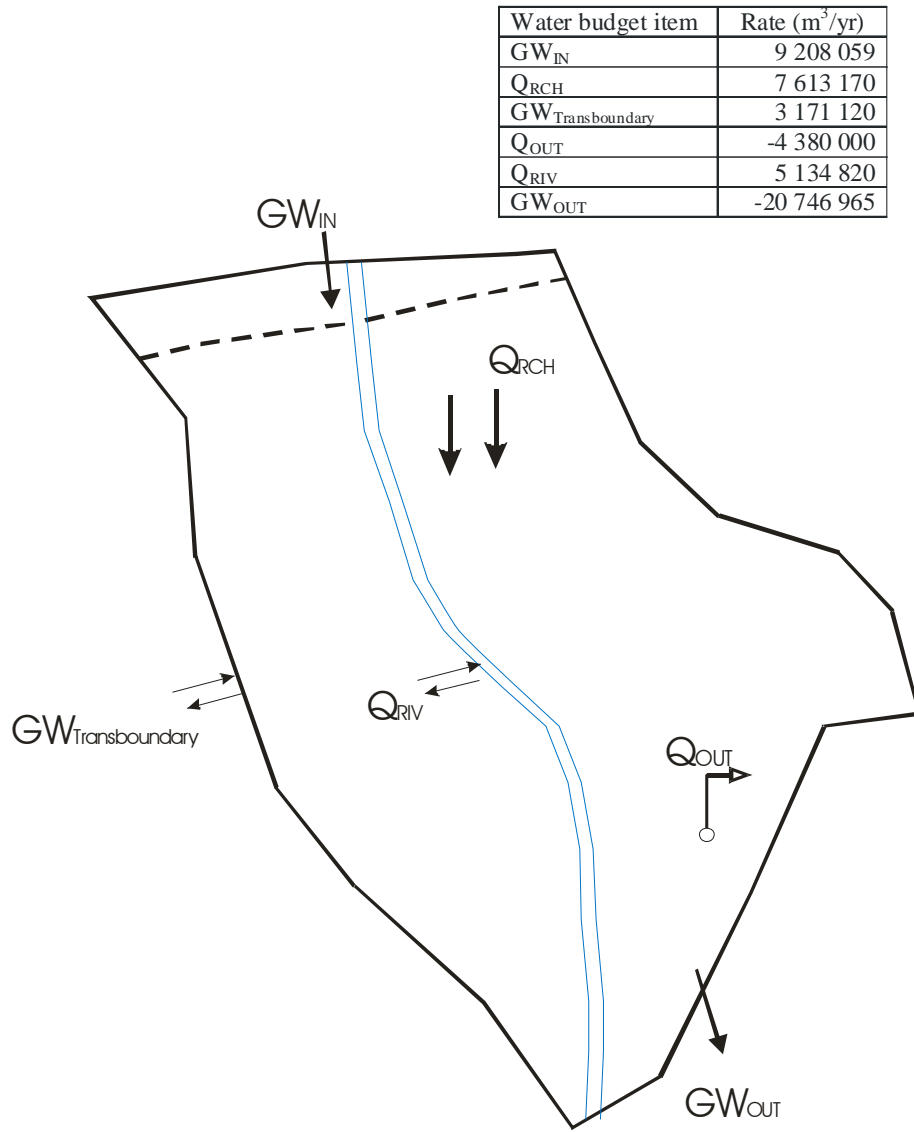
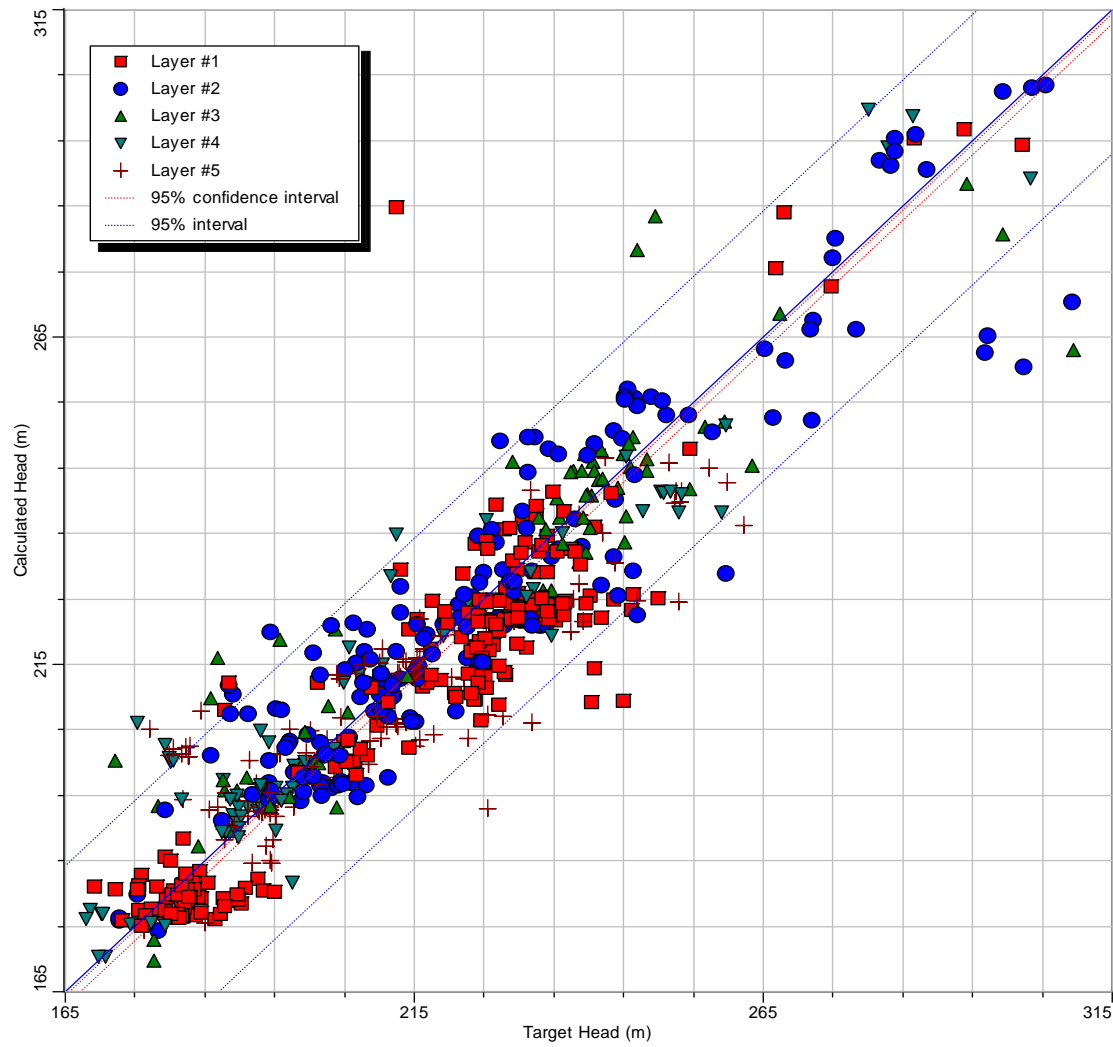


Figure 3.5 Groundwater budget for the East Basin developed with the groundwater model



Num. of Data Points : 686
 Max. Residual: 72.412 (m) at 1333/1333
 Min. Residual: -0.011 (m) at 1724/1724
 Residual Mean : -1.369 (m)
 Abs. Residual Mean : 7.616 (m)

Standard Error of the Estimate : 0.402 (m)
 Root Mean Squared : 10.608 (m)
 Normalized RMS : 7.495 (%)
 Correlation Coefficient : 0.924

Figure 3.6 Comparison of calculated and target water levels, actual pumping rates

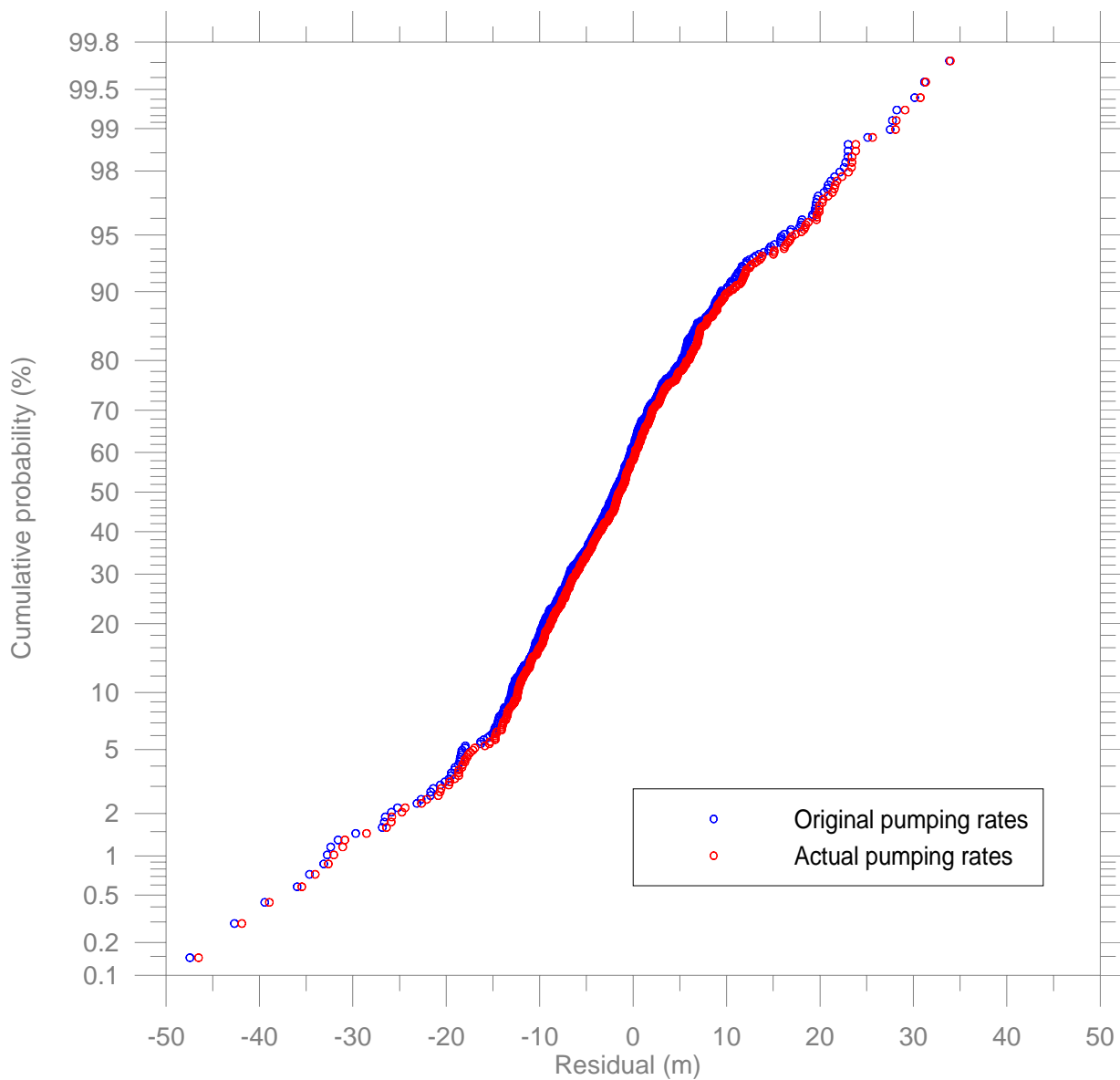


Figure 3.7 Cumulative probability distributions for model residuals

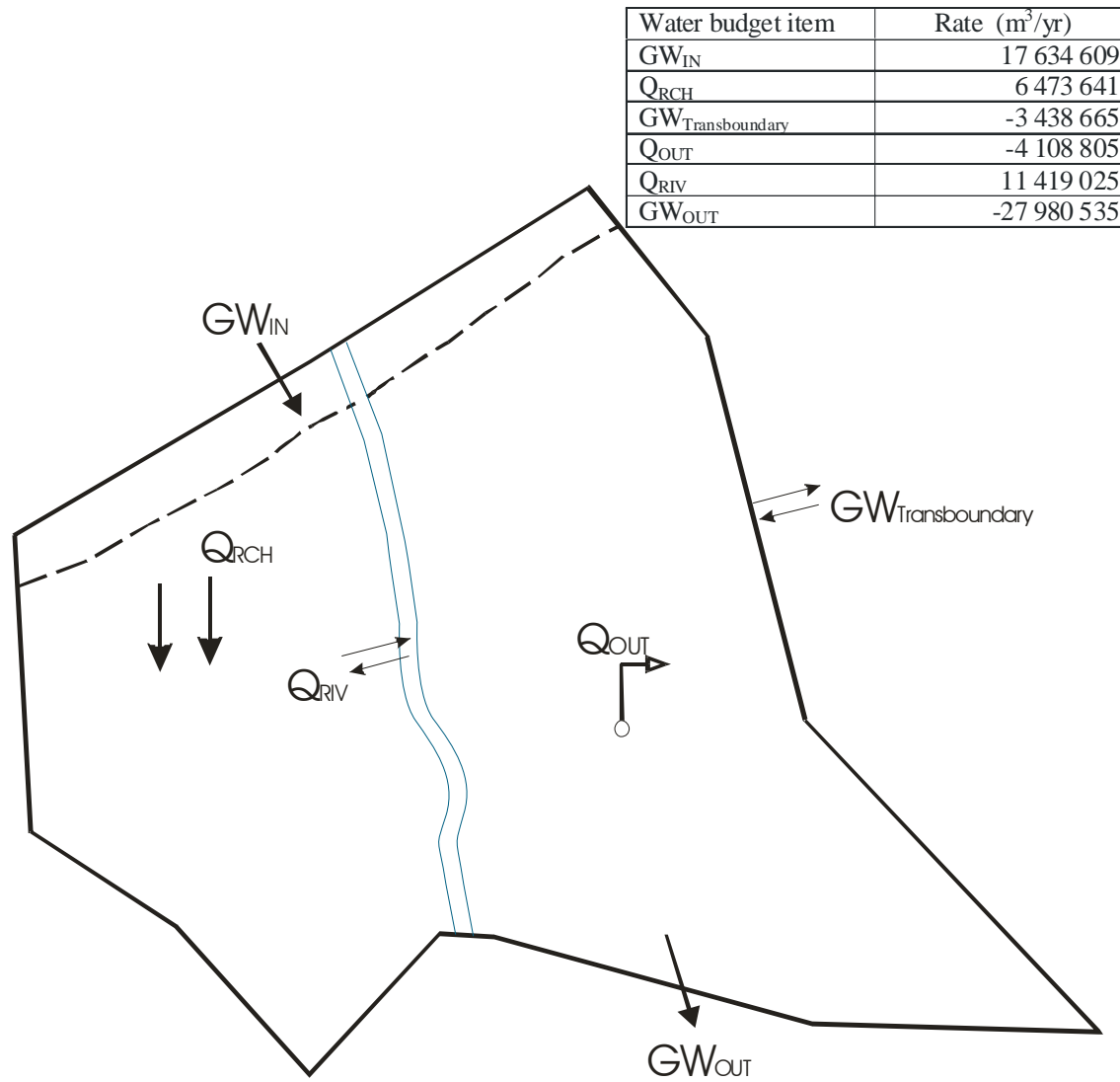


Figure 3.8 Water budget for Central Basin with actual pumping rates

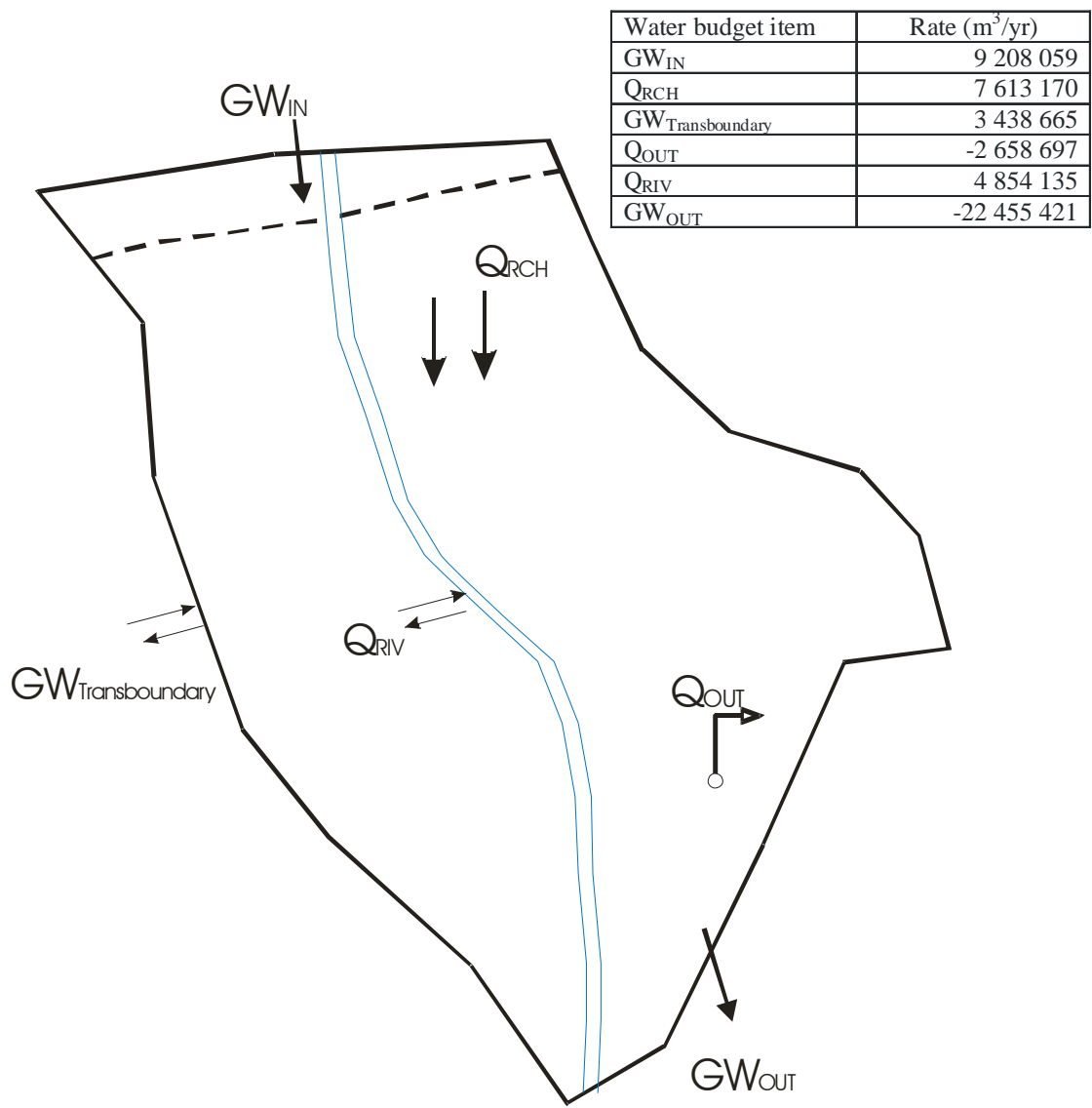


Figure 3.9 Water budget for East Basin with actual pumping rates