# KEEYASK GENERATION PROJECT STAGE IV STUDIES-PHYSICAL ENVIRONMENT GN-9.1.1- EXISTING AND PROJECT ENVIRONMENT FLOW FILES

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DATE: SEPTEMBER 1ST, 2012

**REPORT: PPD #12/08**

Manitoba Hydro

# KEEYASK GENERATION PROJECT

## STAGE IV STUDIES - PHYSICAL ENVIRONMENT

## EXISTING AND PROJECT ENVIRONMENT FLOW FILES

**REV 0**

**DELIVERABLE GN 9.1.1**

**MANITOBA HYDRO FILE: 00195-11100-00136_01**

**2012/09/01**

**PREPARED FOR:**
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INTEROFFICE MEMORANDUM

| From | | TO | |
|---|---|---|---|
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**DATE** 2012 09 01

**FILE** 00195-11100-00136_01

**SUBJECT** **KEEYASK GENERATING STATION – PHYSICAL ENVIRONMENT STUDIES EXISTING AND PROJECT ENVIRONMENT FLOW FILES MEMORANDUM GN-9.1.1-REV 0**

Please find the attached report "Keeyask Generation Project Stage IV Studies - Physical Environment: Existing and Project Environment Flow Files GN-9.1.1". This report documents the development of existing and post-project flow files used in the Stage IV Engineering and Physical Environment Impact Statement studies.

This technical memorandum is to be used in support of the Keeyask Generating Station Environmental Impact Statement. In order to provide appropriate interpretation and guidance, please consult the Water Resource Engineering Department prior to external distribution.

Please contact me at (204) 360-5028 or JMalenchak@hydro.mb.ca if you have any questions or concerns.

Sincerely,

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# TABLE OF CONTENTS

## LIST OF FIGURES



## LIST OF TABLES

# 1 SUMMARY

The Existing Environment inflow file for the Keeyask Generating Station (GS) Environmental Impact Statement (EIS) has been estimated. The Existing Environment inflow file is derived using Kettle GS total outflow discharge, change in storage on Stephens Lake, and local inflow between Kettle GS and Split Lake outlet on a daily time step. The geographic location of the Existing Environment inflow data is located at the Split Lake outlet, and the recommended time period for the existing inflow file is from September 1, 1977 to December 2006. The Post-Project flow file has been calculated with SPLASH modeling outputs. The Post-Project flow regime is based on four scenarios of SPLASH outputs using a time period from April 1912 to March 2006. Various duration curves for the existing environment and post-project flow data have been developed. Results show that the potential flow regime change under the Post-Project scenarios will be minor. With comparisons showing that the flow difference for all percentile values will be less than 10% with the exception of the 5 percentile flow in winter which will realize a difference of 12.2%.

# 2 BACKGROUND

Characterizing the flow regime at the proposed Keeyask GS for both Existing environment and Post-Project is required for the EIS. The proposed GS is located on the Nelson River at Gull Rapids immediately upstream of Stephens Lake (Figure 1). Inflow to the GS is governed by the outflow from Split Lake which is approximately 50 km upstream of the GS. Since no flow records are available at the site of Keeyask GS, inflow to the GS needs to be estimated.

Due to the close proximity to Split Lake, Keeyask inflows can be approximated by Split Lake outflows. In 1977, the Churchill River Diversion (CRD) was constructed, diverting water from the Churchill River into the Burntwood River and eventually into Split Lake. Since there is a noticeable discontinuity in Split Lake discharges after the CRD, only the recorded discharges from Split Lake after 1977 are used to characterize the existing environment.

In order to characterize possible flow regime changes after a new generating station is operational, the SPLASH model was developed by Manitoba Hydro to estimate Post-Project flows. The SPLASH model considers the entire Manitoba Hydro generation system. The model is able to simulate Post-Project flow considering long term inputs into the system and the incorporation of past and future generation components. The SPLASH outputs are flow file scenarios based in terms of a prediction of future electricity loads and generation capacity. In this study, four Post-project flow files at the Keeyask GS are calculated based on SPLASH outputs at the Lake Winnipeg outlet and Notigi Control on a monthly time step. The time period of the post project flow files is from April 1912 to March 2006. Since the model considers long term inputs into the system, this longer post-project flow file (when compared to the existing environment flow file which had a marked discontinuity in 1977 due to the CRD) was considered to be more representative.

# 3 EXISTING ENVIRONMENT FLOW REGIME

## 3.1 LOCAL INFLOW ESTIMATION

In order to estimate daily inflows to the Keeyask GS for the existing environment, local inflows between the Split Lake outlet and the Kettle GS were first computed. This study uses the rational method for local inflow estimation. The Kettle River basin is selected as an index basin since it neighbors the local inflow basin between the Split Lake outlet and Kettle GS. The recorded daily discharge at hydrometric station (05UF004) on the Kettle River was extracted from the Water Survey of Environment Canada data sets. The area of the Kettle River basin and the local inflow sub-basin was computed using ArcGIS. The geographic location of the relevant sub-basins and generating stations are illustrated in Figure 1. Figure 2 shows the estimated daily local inflow hydrograph.

## 3.2 KEEYASK GS INFLOW CALCULATION

In the hydraulic system between Split Lake Outlet and the Kettle GS, a mass conservation equation for a daily time step can be given by:

$$\frac{dS_{\text{Stephens}}}{dt} \approx \frac{\Delta S_{\text{Stephens}}}{\Delta t} = \frac{f(H+\Delta H)-f(H)}{\Delta t} = -Q_{\text{Kettle GS}} + Q_{\text{Local}} + Q_{\text{Keeyask GS}} \quad (1)$$

where

$S_{\text{Stephens}}$ = Storage in Stephens Lake for a given day;

$\Delta S_{\text{Stephens}}$ = Storage change in Stephens Lake for a given day;

$f(H)$ = Stage-storage relation function;

$\Delta H$ = Daily water surface elevation change in Stephens Lake;

$Q_{\text{Kettle GS}}$ = Total daily outflow at the Kettle GS;

$Q_{\text{Local}}$ = Daily local inflow between Split Lake outlet and Kettle GS;

$Q_{\text{Keeyask GS}}$ = Daily inflow to the Keeyask GS at the Split lake outlet;

$\Delta t$ = 24 hours.

At the Kettle GS forebay, a stage-storage relationship equation is developed, graphically depicted in Figure 3. In reality, average water surface elevation changes on Stephens lake ($\Delta H$) and the elevation changes measured at the Kettle GS forebay are often different since the flow at Stephens Lake can be unsteady varied flow. In order to use the storage-elevation equation depicted in Figure 3, equation (1) is transformed into:

$$\begin{aligned} Q_{\text{Keeyask GS}} &= Q_{\text{Kettle GS}} - Q_{\text{Local}} + \left(\frac{f(H_0 + \Delta H_0) - f(H_0)}{\Delta t} + \frac{\Delta S'}{\Delta t}\right) \\ &= \left(Q_{\text{Kettle GS}} - Q_{\text{Local}} + \frac{\Delta S}{\Delta t}\right) + \frac{\Delta S'}{\Delta t} = Q_{\text{cal}} + \Delta Q' \end{aligned} \qquad (2)$$

where $H_0$ is water surface elevation at the Kettle GS forebay; $\Delta H_0$ is water surface elevation change at the forebay; $\Delta S$ is storage change on Stephens Lake calculated by the equation shown in Figure 3; and $\Delta S'$ is the adjustment of storage change $\Delta S$; and $\Delta Q'$ is the relevant discharge adjustment corresponding to $\Delta S'$.

Since the values of $\Delta Q'$ are unknown, a practical way to estimate the value of $Q_{\text{Keeyask GS}}$ is to take multi-day moving average of the calculated values $Q_{\text{cal}}$. In this study, the multi-day moving average is taken using intervals that range from 2 to 8 days. Since an open water rating curve is developed at the Split Lake outlet, the following criterion is used to select the best existing environment flow file using the multi-day moving average values.

$$\text{Min } E! = \sqrt{\sum (q_{\text{i}}^{\text{Keeyask GS}} - q_i^{\textit{Split Lake}})^2} \qquad (3)$$

where $q_{\text{i}}^{\text{Keeyask GS}}$ is the Keeyask GS open water daily flow found using the multi-day moving average of $Q_{\text{Keeyask GS}}$; $q_i^{\textit{Split Lake}}$ is Split lake outlet open water daily flow calculated using the rating curve; and the minimum value of E! indicates the best estimate.

In the process of calculation, daily outflow discharge data at the Kettle GS and 24-hour end water level elevation on Stephens Lake were extracted from the Manitoba Hydro Daily Hydrometric Database. The open water rating curve at the Split Lake outlet shown in Figure 4 was referenced from "*Keeyask Generating Station Stage 4 Studies Updated Open Water Hydraulics Memorandum GN-2.1, Draft 2, April 21, 2005*" (Manitoba Hydro, 2004). The rating curve was used to generate the daily flow file ($q_i^{\textit{Split Lake}}$) at the Split Lake outlet based on observed water level data.

It was found that the 7-day moving average daily flow file is the best estimate for the inflow to the Keeyask GS under existing environment conditions. As a result, the flow file by taking the 7-day moving average of the flow data calculated from equation (1) is used as the estimated inflow to the Keeyask GS. Figure 5 illustrates the estimated Keeyask GS daily flow hydrograph, and the corresponding monthly average flow hydrograph is shown in Figure 6.

### 3.3 Existing Environment Flow Duration Curves

The estimated Keeyask GS daily inflow file was used to develop the existing environment duration curves. Figure 7 illustrates the daily flow duration curves for the existing environment, and the corresponding monthly average discharge duration curves are demonstrated in Figure 8. For reference purposes, open water season is defined as May 1 – Oct. 31 in this study and the winter season would therefore be defined as Nov. 1 – Apr. 30.

# 4 POST-PROJECT FLOW REGIME

### 4.1 Post-project Flow Files

According to the possible time schedule of building Conawapa and Keeyask GS and the projection of future electricity load of the entire system, four SPLASH Post-Project flow files are selected in this study. Each Post-Project file is based on a corresponding scenario of electricity load and generation capacity as follows:

- Existing_2008 (existing capacity with load year 2008)
- Conawapa_2023 (existing capacity plus Conawapa GS with load year 2023)
- Conawapa + Keeyask + IC_2023 (existing capacity plus Conawapa plus Keeyask plus Inter-Connection with load year 2023)
- Single Cycle Combustion Turbine (SCCT)_2023 (existing capacity plus SCCT with load year 2023)

It should be noted that the system load of 2023 could occur any time in the future. Since the SPLASH modeled monthly discharges are located at the Lake Winnipeg outlet and Notigi Control, the Post-Project inflows to the Keeyask GS under a given scenario were computed by adding them to the local inflows (inflow between Lake Winnipeg outlet/Notigi Control and the Split Lake outlet). Local inflows were calculated based on the methodology described in the long term streamflow data technical reports (Manitoba Hydro, 1990). Figure 9 demonstrates the computed Post-Project flow files at the Keeyask GS.

### 4.2 Post-project flow regime

The duration curve corresponding to each scenario of computed Post-Project flow file for the Keeyask GS was developed separately for all season, open water, and winter, as shown in Figures 10-12. The figures also illustrate the Post-Project mean flow duration curve which is developed by putting all-scenario flow data together. The graphs show both the variation among Post-project flow files and their deviation against the mean values.

For the Post-project flow files, a representative flow file from the four flow files needs to be selected in order to obtain the hydrograph to be used in the EIS. This study uses a least-square method to identify a representative Post-project flow file, which is chosen based on the maximum least-square value between the mean flow (all scenarios) duration curve values and each Post-project flow file duration curve values. The results show that the Conawapa+Keeyask+IC_2023 scenario has the most representative Post-project flow file. Table 1 lists the Post-project flow data of the representative scenario.

# 5 DISCUSSION AND CONCLUSIONS

Figures 13-15 show a comparison of the duration curves for the Existing Environment monthly flow data and the Conawapa+Keeyask+IC_2023 inflow file for all-season, open water, and winter, respectively. The comparison shows that the flow difference for different percentile values is small since the difference is less than 10% except when considering the 5 percentile flow in winter (12.2% difference). The difference between the two flow files is also associated with two different periods being used in Existing Environment (1977-2006) and Post-Project (1912-2006). Therefore, the potential flow regime change under the Post-Project environment will be minor. A comparison of the Existing Environment and Post-Project monthly flow data for identical time periods (1977-2006) can be found in Figure 16. The purpose of this illustration is to show that the SPLASH output compares well with existing environment measured data for the same time period.

# 6 GLOSSARY

| | |
|---|---|
| ***existing environment*** | Refers to the environment in which a proposed generating station is to be built, under the conditions that exist prior to it actually being built. |
| ***forebay*** | A reservoir feeding the intake of a hydroelectric power plant. |
| ***inflow*** | Refers to flow discharge to a reservoir/lake/forebay. |
| ***least-squares analysis*** | A statistical procedure that determines the minimum value, among a set of alternatives, of the numerical difference between two series raised to the second power. |
| ***outflow*** | Refers to flow discharge from a reservoir/lake. |
| ***post-project*** | Refers to the environment in which a proposed generating station is to be built, under the conditions that exist after it has been built. |
| ***SPLASH*** | Manitoba Hydro’s comprehensive long term resource planning analysis tool, which evaluates system-wide energy production and benefits of various system expansion options under current and future load scenarios. |

# 7 REFERENCES

Manitoba Hydro (1990), Long Term Streamflow Data Phase II, Stage I: Streamflow Data Extension 1968 to 1988 Period. T. M. No. 90/4-1.

Manitoba Hydro (2005), Keeyask Generating Station Stage IV Studies Updated Open Water Hydraulics Memorandum GN-2.1, Rev 0.

# 8 APPENDIX A - ABBREVIATIONS

# ABBREVIATIONS

cms........................................cubic metres per second

CRD......................................Churchill River Diversion

EIS........................................environmental impact statement

GS.........................................generating station

IC..........................................inter-connection

km.........................................kilometre

m...........................................metre

SCCT ....................................single cycle combustion turbine

# 9 APPENDIX B - FIGURES AND TABLES

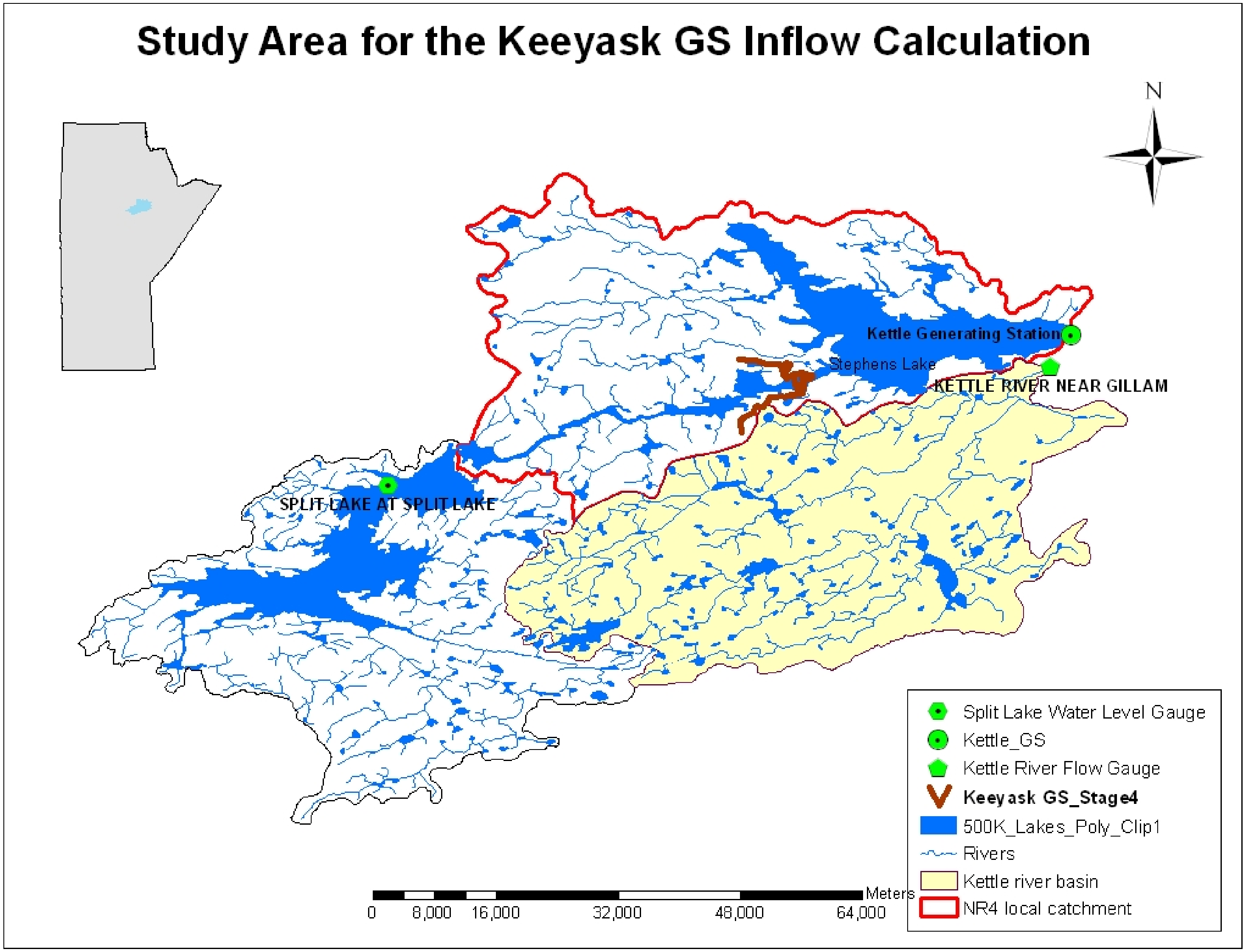



**Figure 1 Study area**

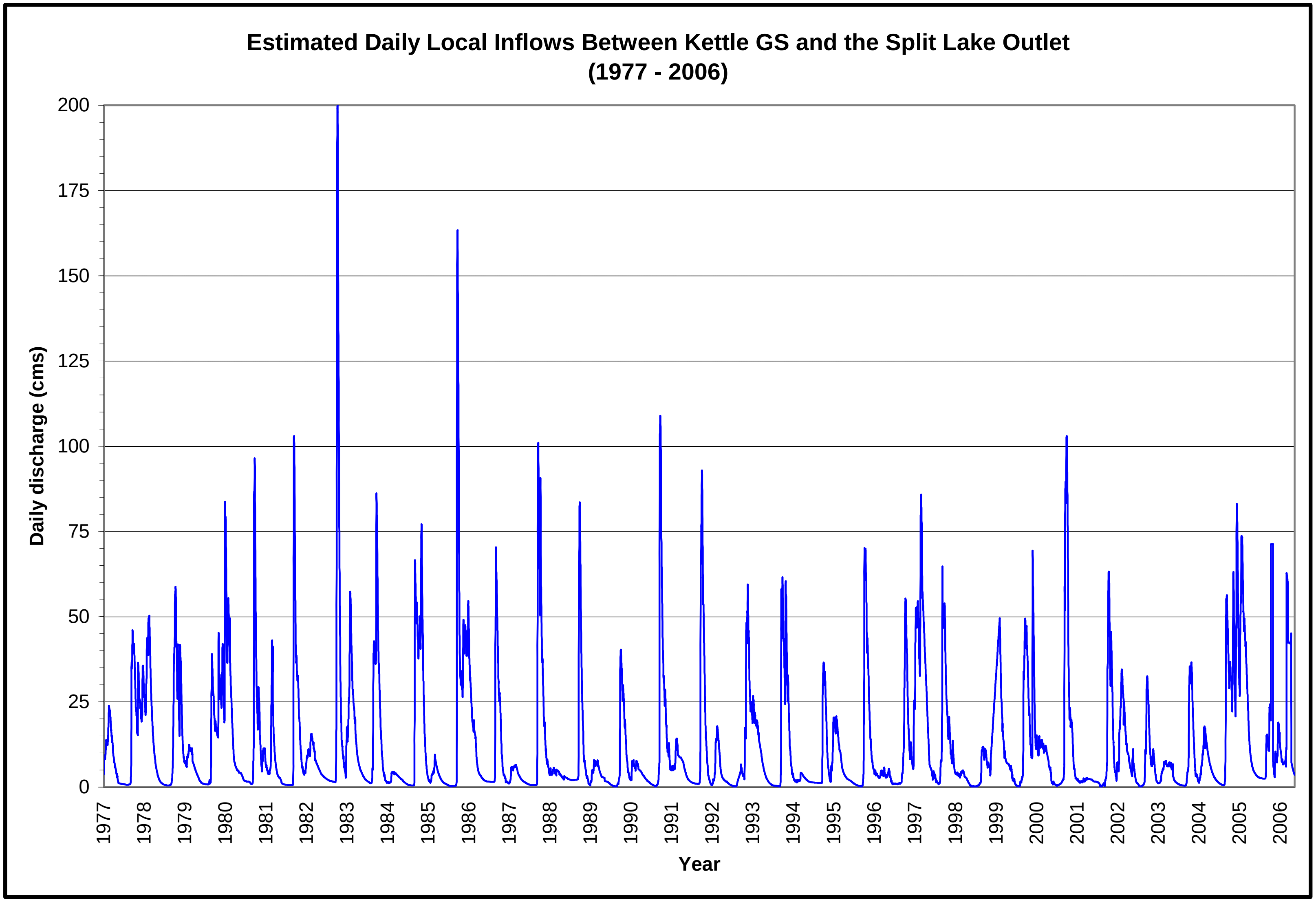
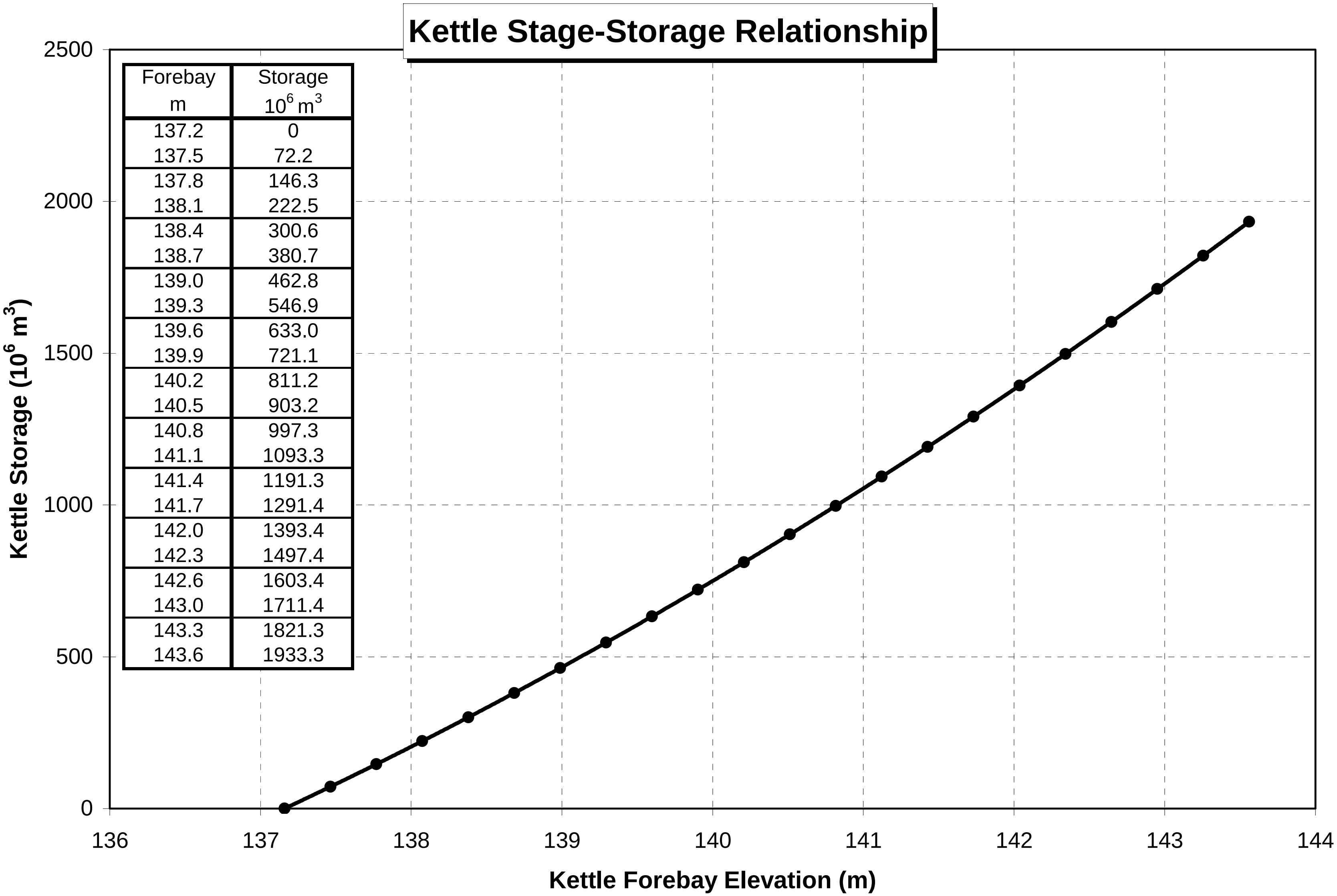



**Figure 2 Estimated daily local inflow hydrograph (1977 – 2006)**




| Forebay m | Storage $10^6$ $m^3$ |
|---|---|
| 137.2 | 0 |
| 137.5 | 72.2 |
| 137.8 | 146.3 |
| 138.1 | 222.5 |
| 138.4 | 300.6 |
| 138.7 | 380.7 |
| 139.0 | 462.8 |
| 139.3 | 546.9 |
| 139.6 | 633.0 |
| 139.9 | 721.1 |
| 140.2 | 811.2 |
| 140.5 | 903.2 |
| 140.8 | 997.3 |
| 141.1 | 1093.3 |
| 141.4 | 1191.3 |
| 141.7 | 1291.4 |
| 142.0 | 1393.4 |
| 142.3 | 1497.4 |
| 142.6 | 1603.4 |
| 143.0 | 1711.4 |
| 143.3 | 1821.3 |
| 143.6 | 1933.3 |

**Figure 3 Stage-storage relationship at Stephens Lake (Kettle Forebay)**

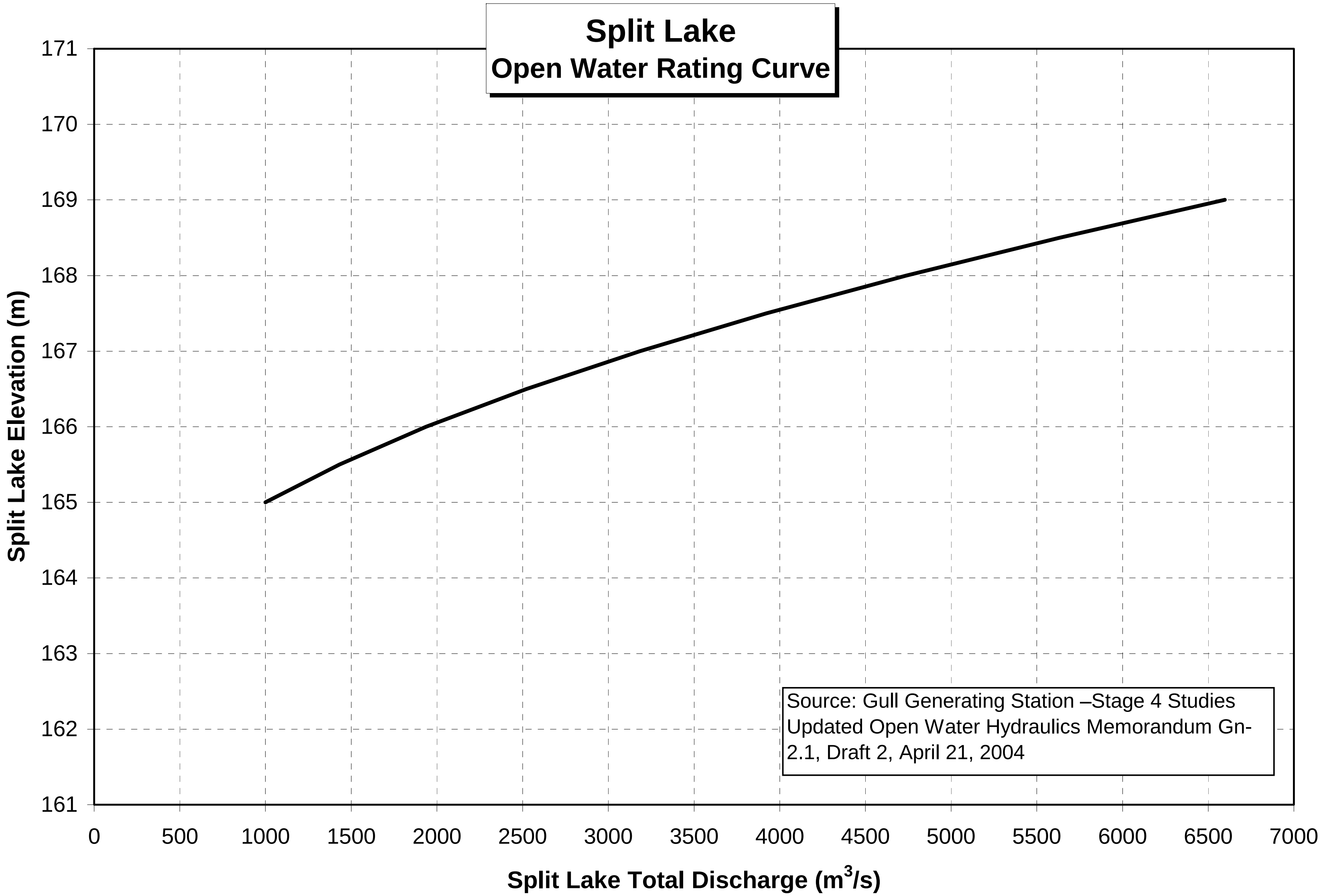



**Figure 4 Split Lake open water rating curve**

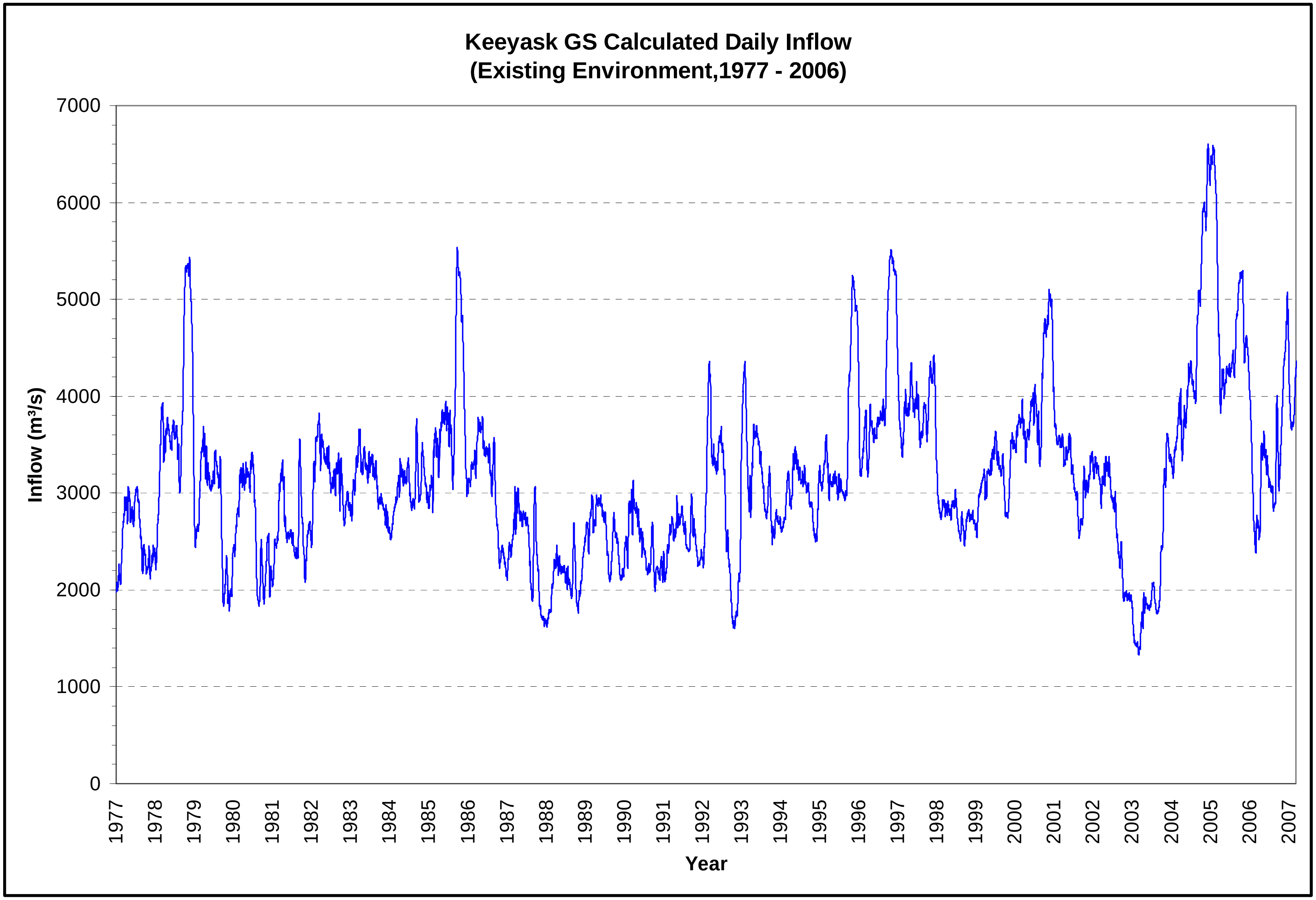



**Figure 5 Keeyask GS calculated daily inflow hydrograph (1977 – 2006)**

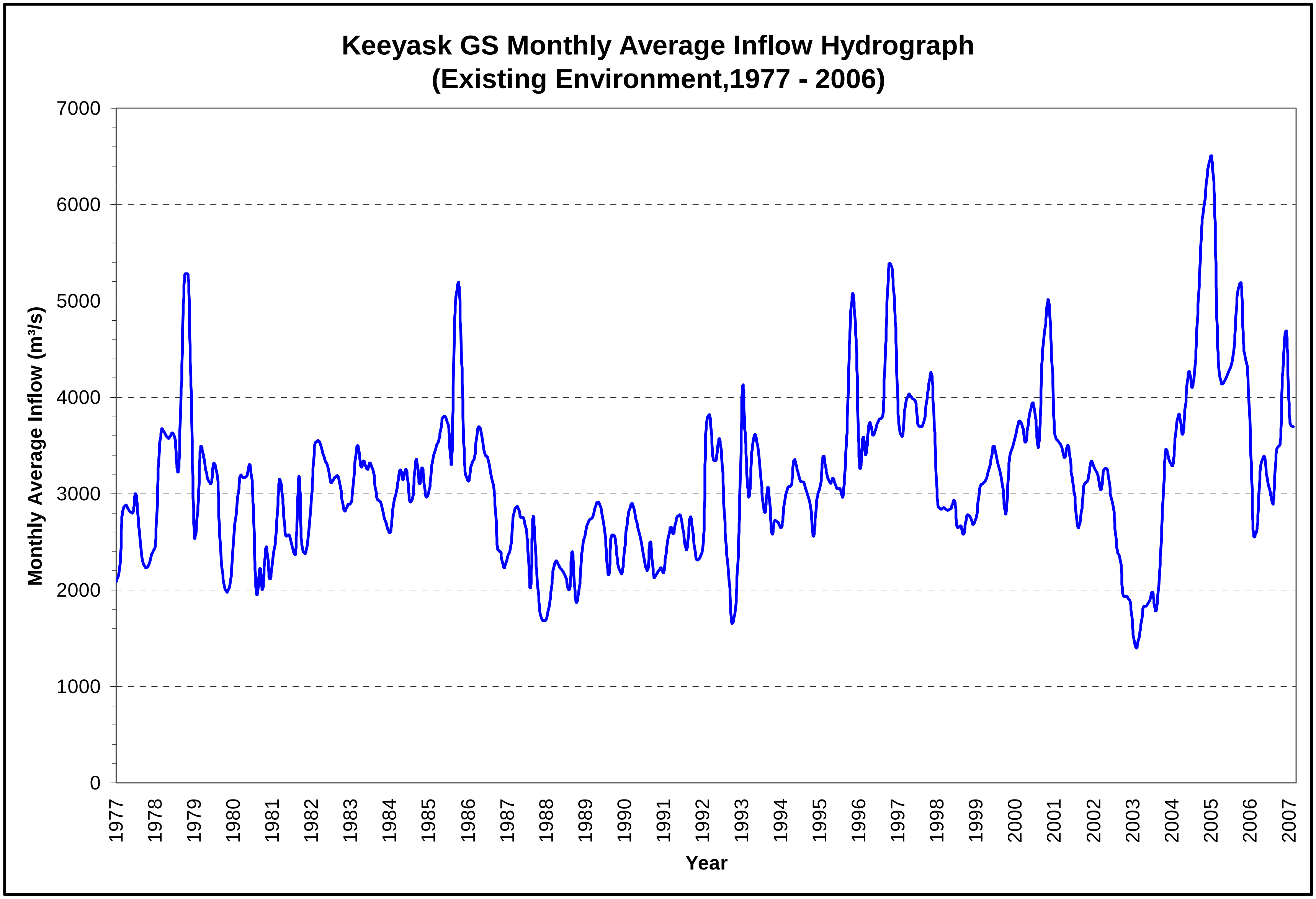
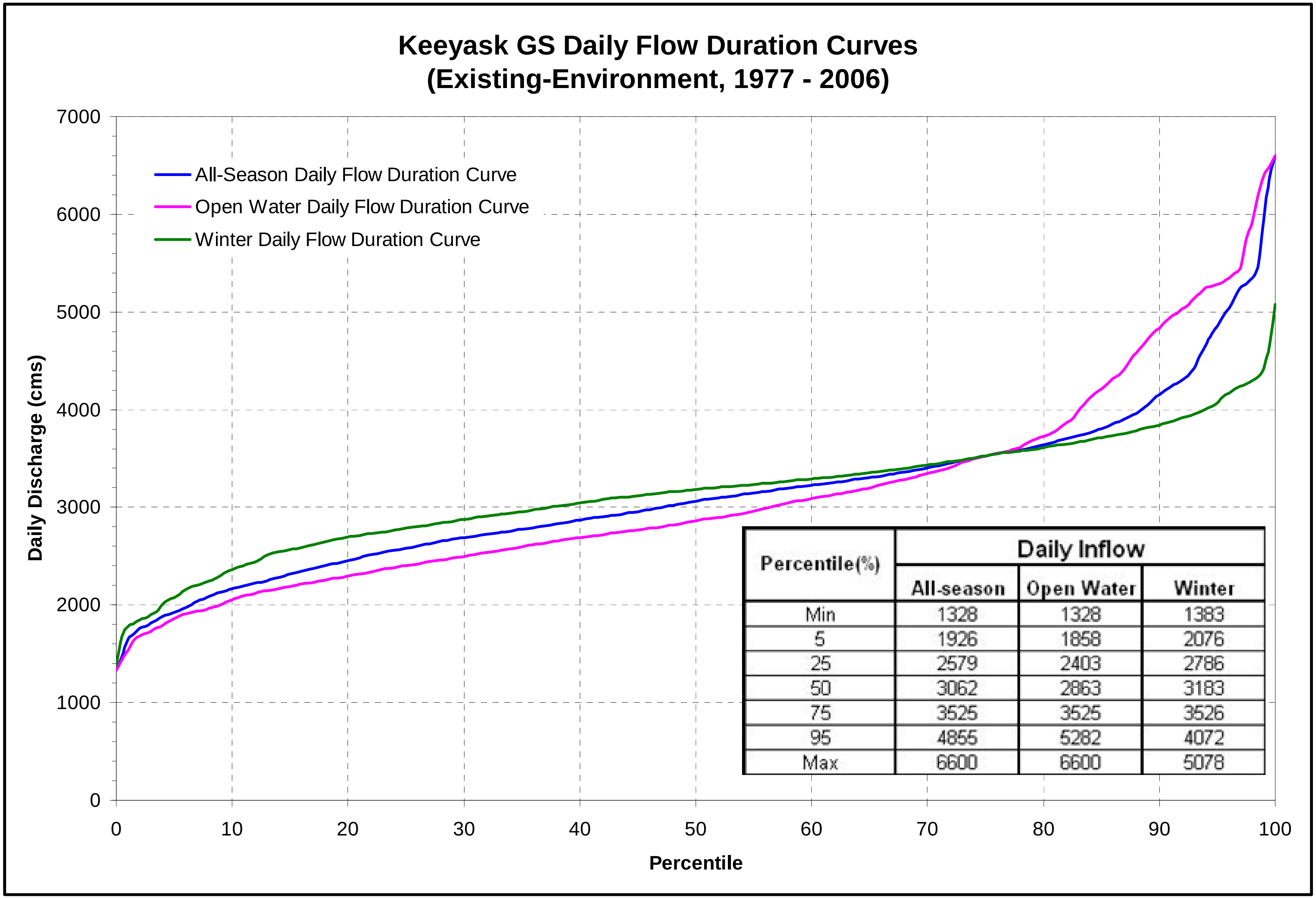
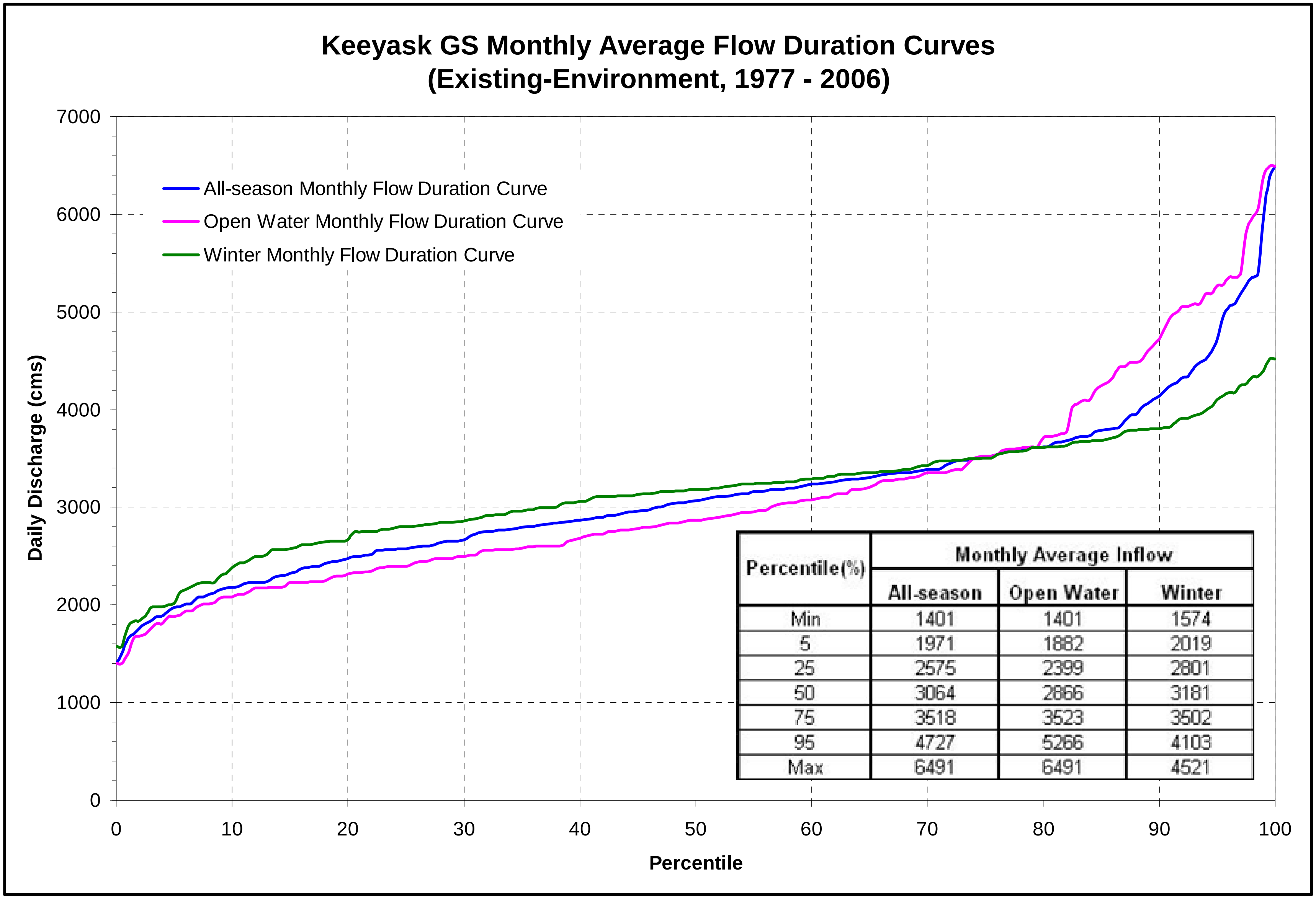



**Figure 6 Keeyask GS monthly average inflow hydrograph (1977 – 2006)**




| Percentile(%) | Daily Inflow | | |
|---|---|---|---|
| | All-season | Open Water | Winter |
| Min | 1328 | 1328 | 1383 |
| 5 | 1926 | 1858 | 2076 |
| 25 | 2579 | 2403 | 2786 |
| 50 | 3062 | 2863 | 3183 |
| 75 | 3525 | 3525 | 3526 |
| 95 | 4855 | 5282 | 4072 |
| Max | 6600 | 6600 | 5078 |

**Figure 7 Keeyask GS existing environment daily inflow duration curves (1977 – 2006)**




| Percentile(%) | Monthly Average Inflow | | |
|---|---|---|---|
| | All-season | Open Water | Winter |
| Min | 1401 | 1401 | 1574 |
| 5 | 1971 | 1882 | 2019 |
| 25 | 2575 | 2399 | 2801 |
| 50 | 3064 | 2866 | 3181 |
| 75 | 3518 | 3523 | 3502 |
| 95 | 4727 | 5266 | 4103 |
| Max | 6491 | 6491 | 4521 |

**Figure 8 Keeyask GS existing environment monthly average inflow duration curves (1977 – 2006)**

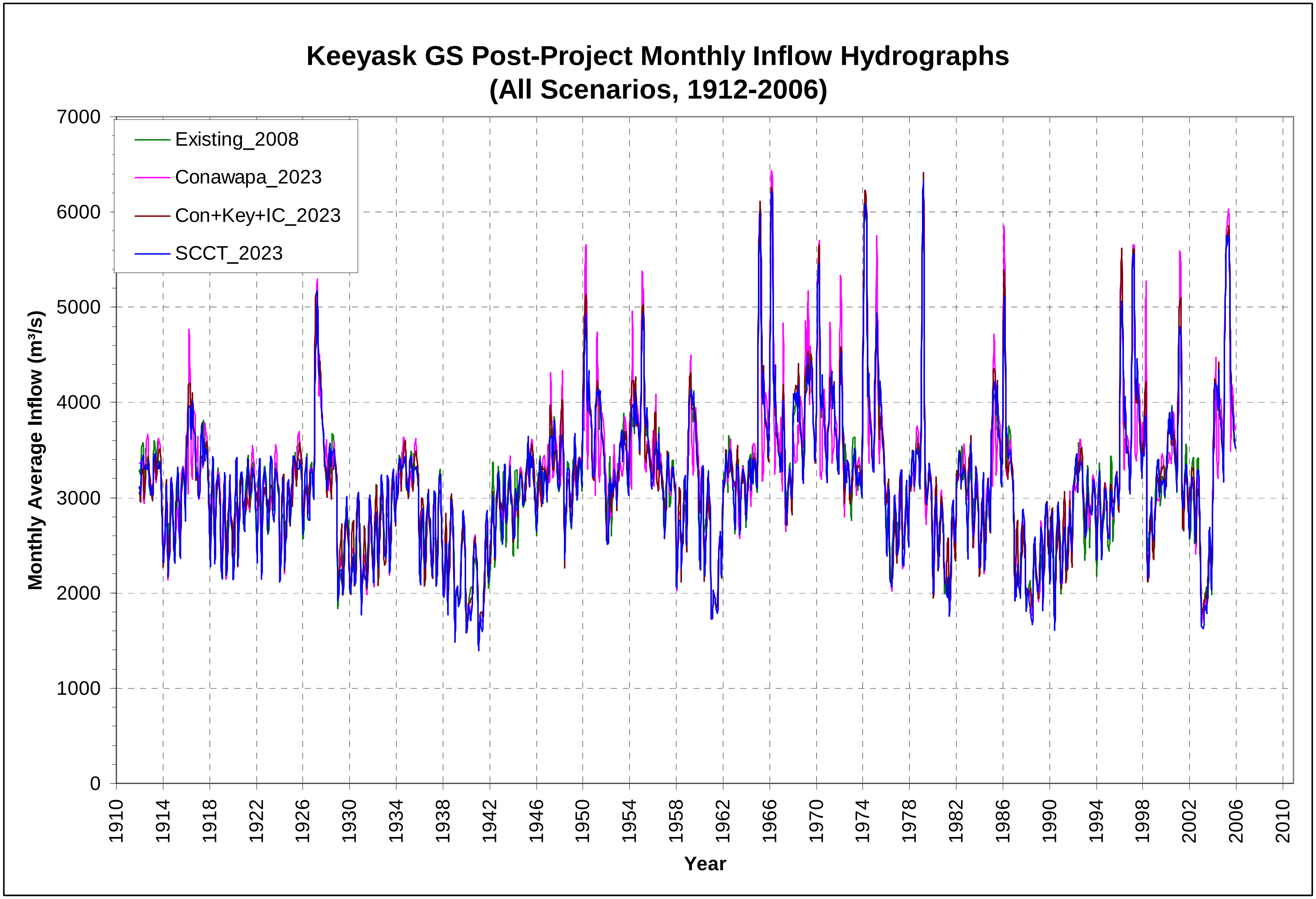
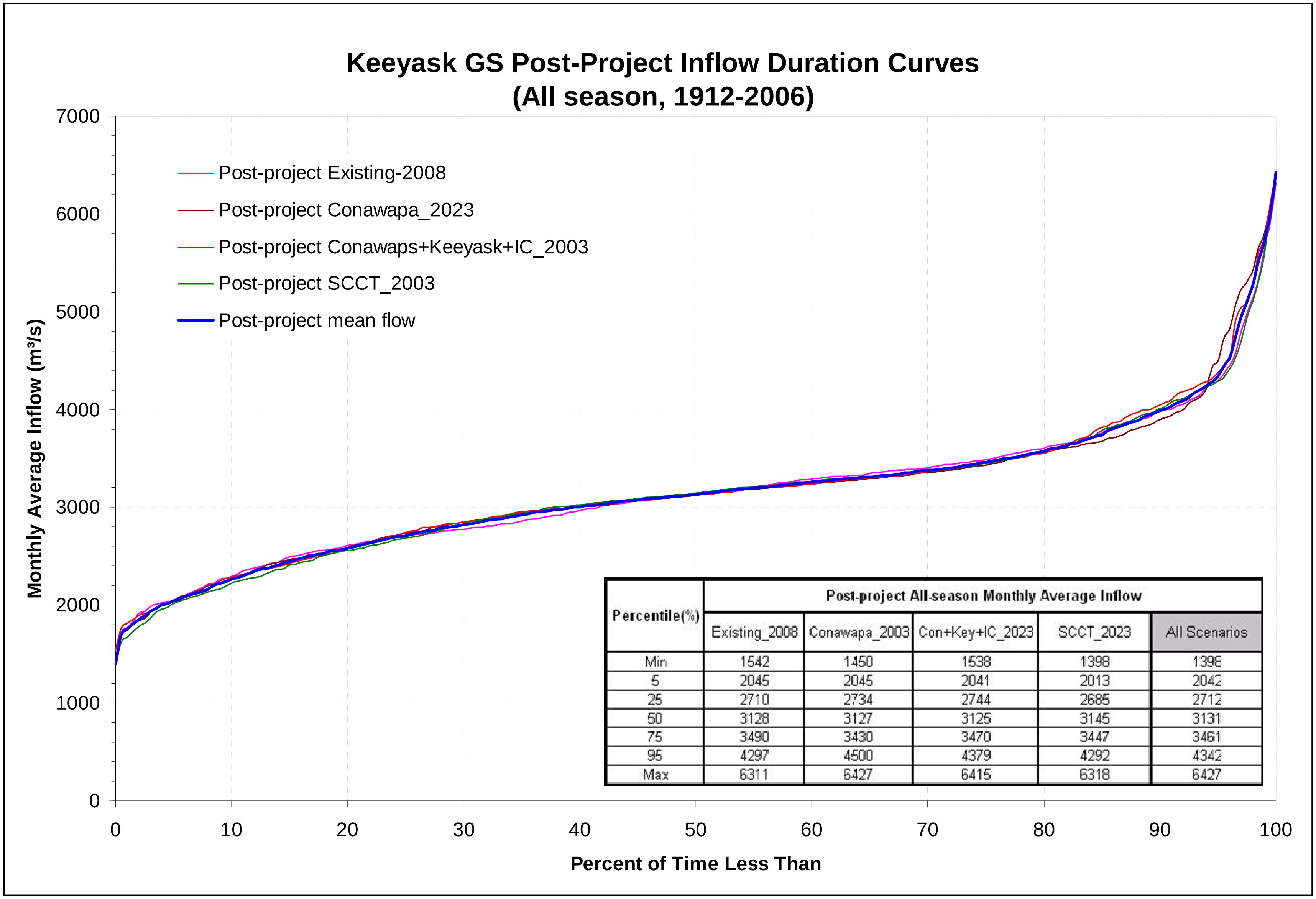
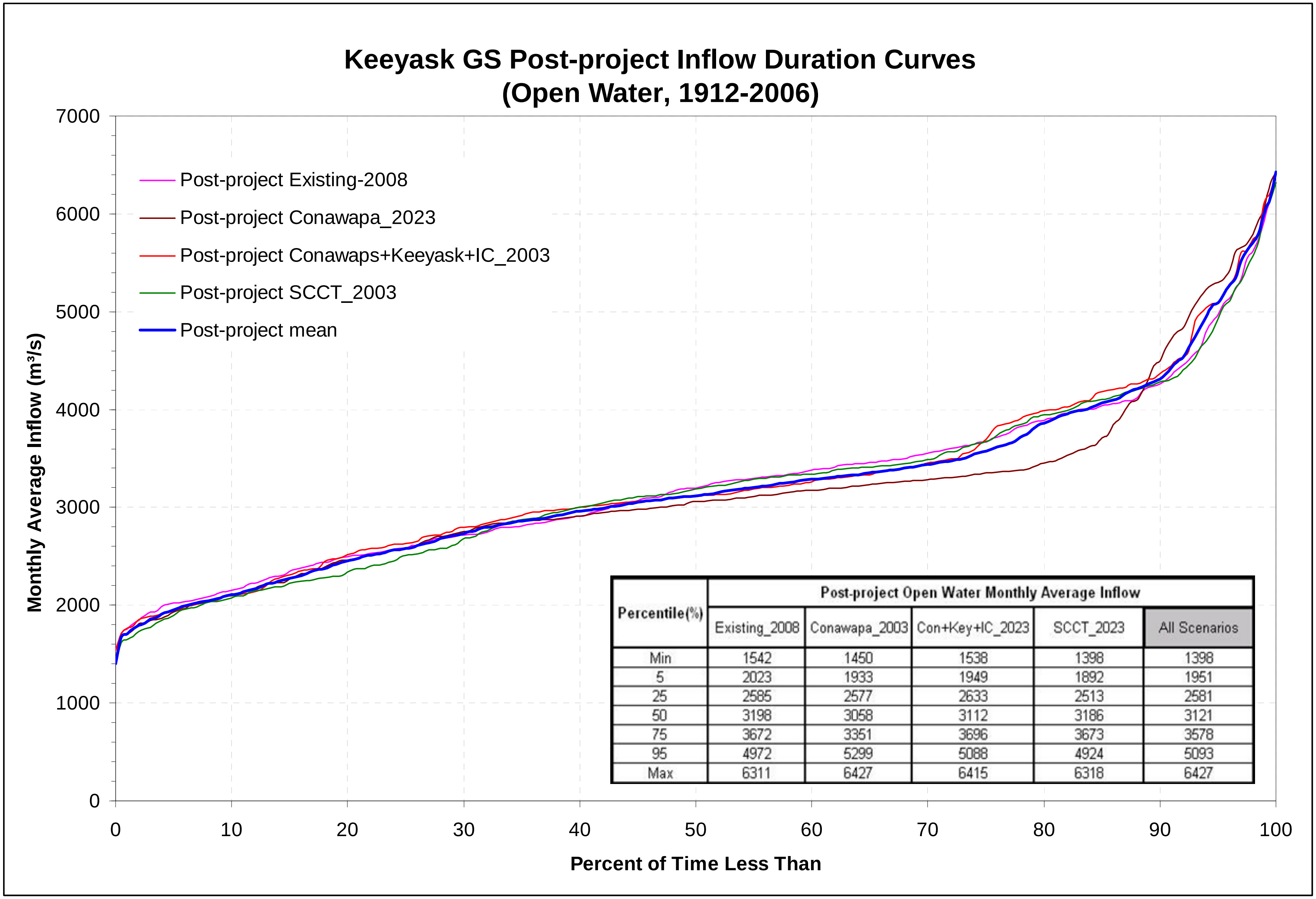



**Figure 9 Keeyask GS Post-Project inflow hydrographs (1912 – 2006)**



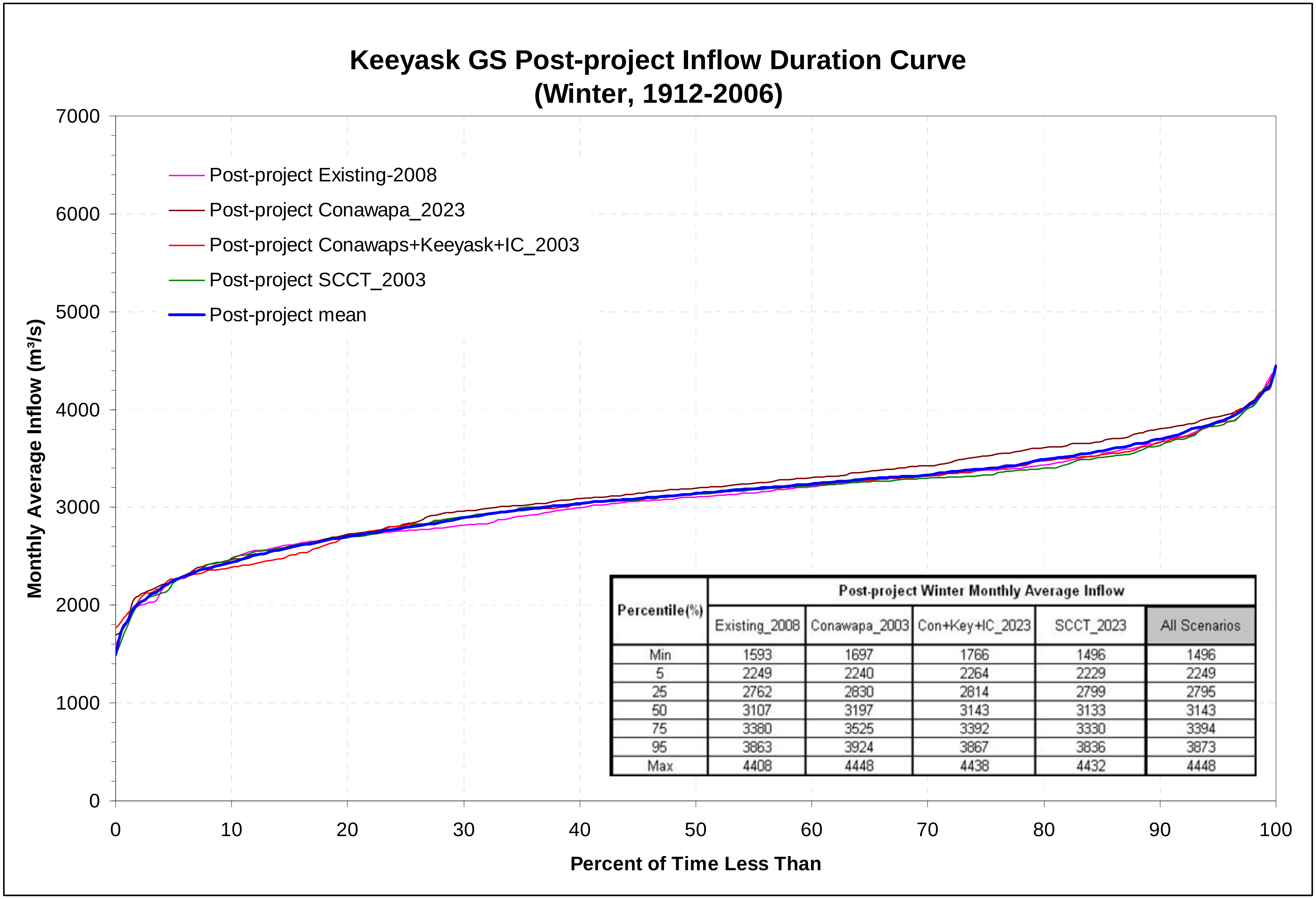

| Percentile(%) | Post-project All-season Monthly Average Inflow | | | | |
|---|---|---|---|---|---|
| | Existing_2008 | Conawapa_2003 | Con+Key+IC_2023 | SCCT_2023 | All Scenarios |
| Min | 1542 | 1450 | 1538 | 1398 | 1398 |
| 5 | 2045 | 2045 | 2041 | 2013 | 2042 |
| 25 | 2710 | 2734 | 2744 | 2685 | 2712 |
| 50 | 3128 | 3127 | 3125 | 3145 | 3131 |
| 75 | 3490 | 3430 | 3470 | 3447 | 3461 |
| 95 | 4297 | 4500 | 4379 | 4292 | 4342 |
| Max | 6311 | 6427 | 6415 | 6318 | 6427 |

**Figure 10 Post-Project all-season inflow duration curves (1912 – 2006)**



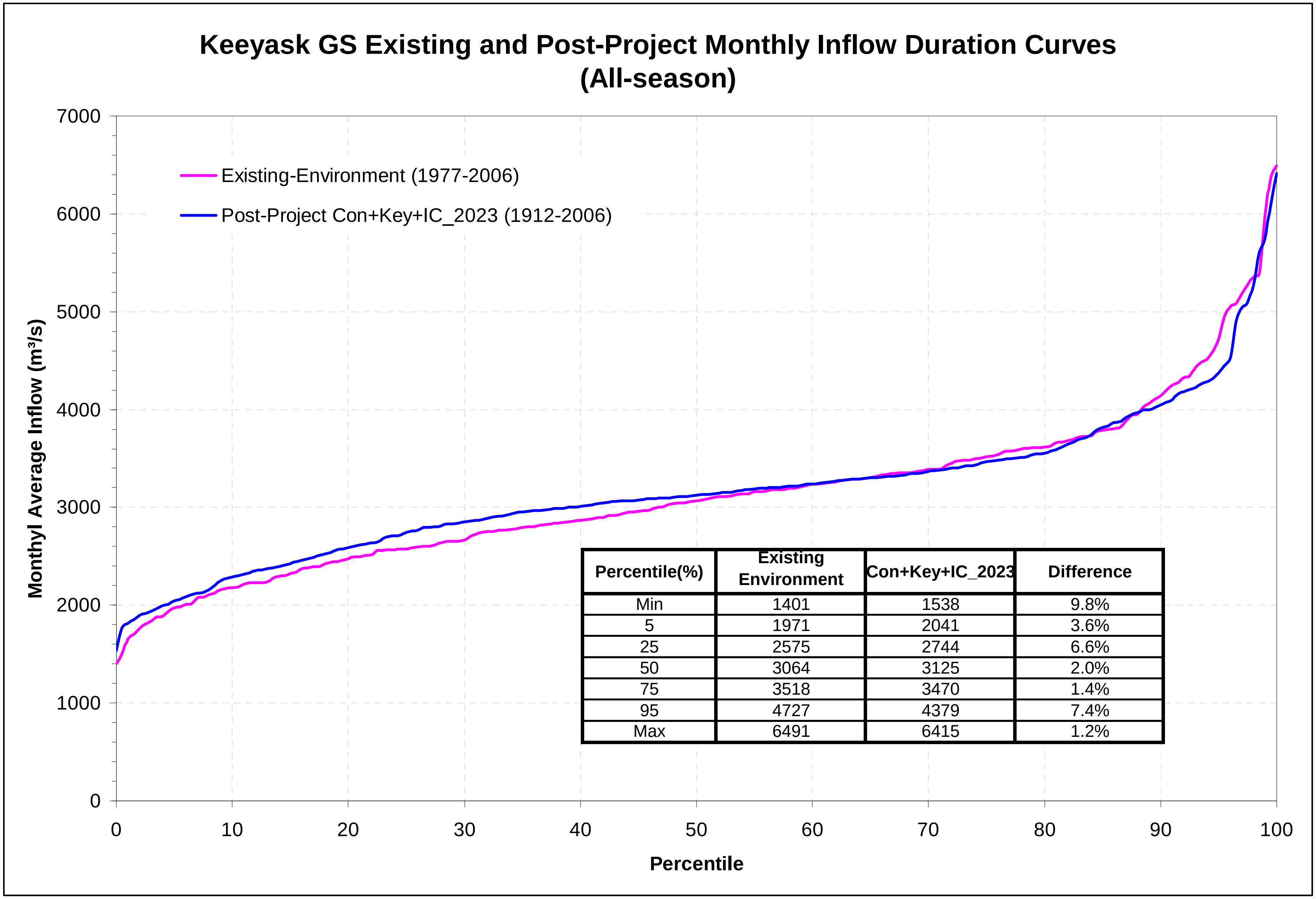

| Percentile(%) | Post-project Open Water Monthly Average Inflow | | | | |
|---|---|---|---|---|---|
| | Existing_2008 | Conawapa_2003 | Con+Key+IC_2023 | SCCT_2023 | All Scenarios |
| Min | 1542 | 1450 | 1538 | 1398 | 1398 |
| 5 | 2023 | 1933 | 1949 | 1892 | 1951 |
| 25 | 2585 | 2577 | 2633 | 2513 | 2581 |
| 50 | 3198 | 3058 | 3112 | 3186 | 3121 |
| 75 | 3672 | 3351 | 3696 | 3673 | 3578 |
| 95 | 4972 | 5299 | 5088 | 4924 | 5093 |
| Max | 6311 | 6427 | 6415 | 6318 | 6427 |

**Figure 11 Post-Project open water inflow duration curves (1912 – 2006)**



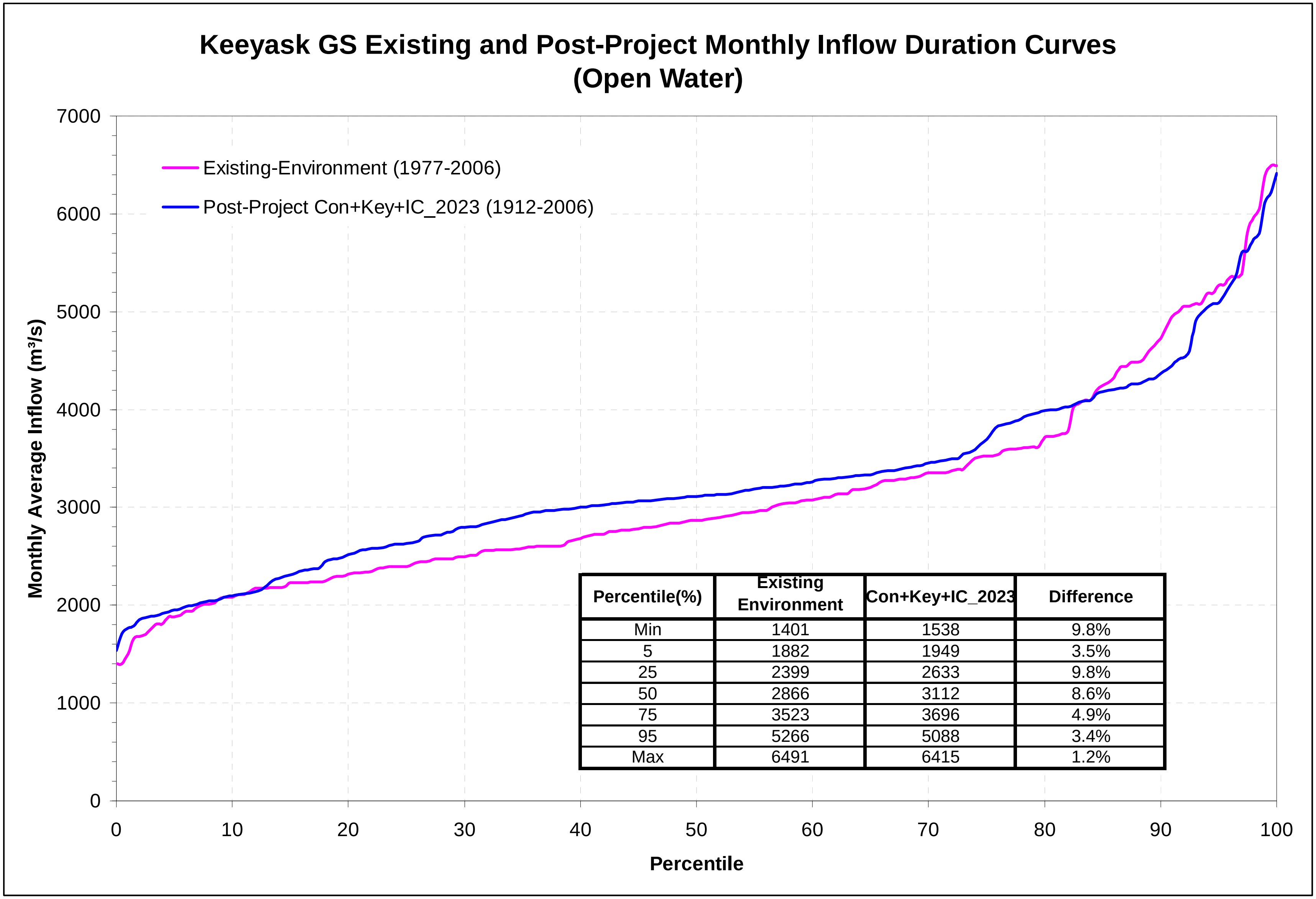

| Percentile(%) | Post-project Winter Monthly Average Inflow | | | | |
|---|---|---|---|---|---|
| | Existing_2008 | Conawapa_2003 | Con+Key+IC_2023 | SCCT_2023 | All Scenarios |
| Min | 1593 | 1697 | 1766 | 1496 | 1496 |
| 5 | 2249 | 2240 | 2264 | 2229 | 2249 |
| 25 | 2762 | 2830 | 2814 | 2799 | 2795 |
| 50 | 3107 | 3197 | 3143 | 3133 | 3143 |
| 75 | 3380 | 3525 | 3392 | 3330 | 3394 |
| 95 | 3863 | 3924 | 3867 | 3836 | 3873 |
| Max | 4408 | 4448 | 4438 | 4432 | 4448 |

**Figure 12 Post-project winter inflow duration curves (1912 – 2006)**



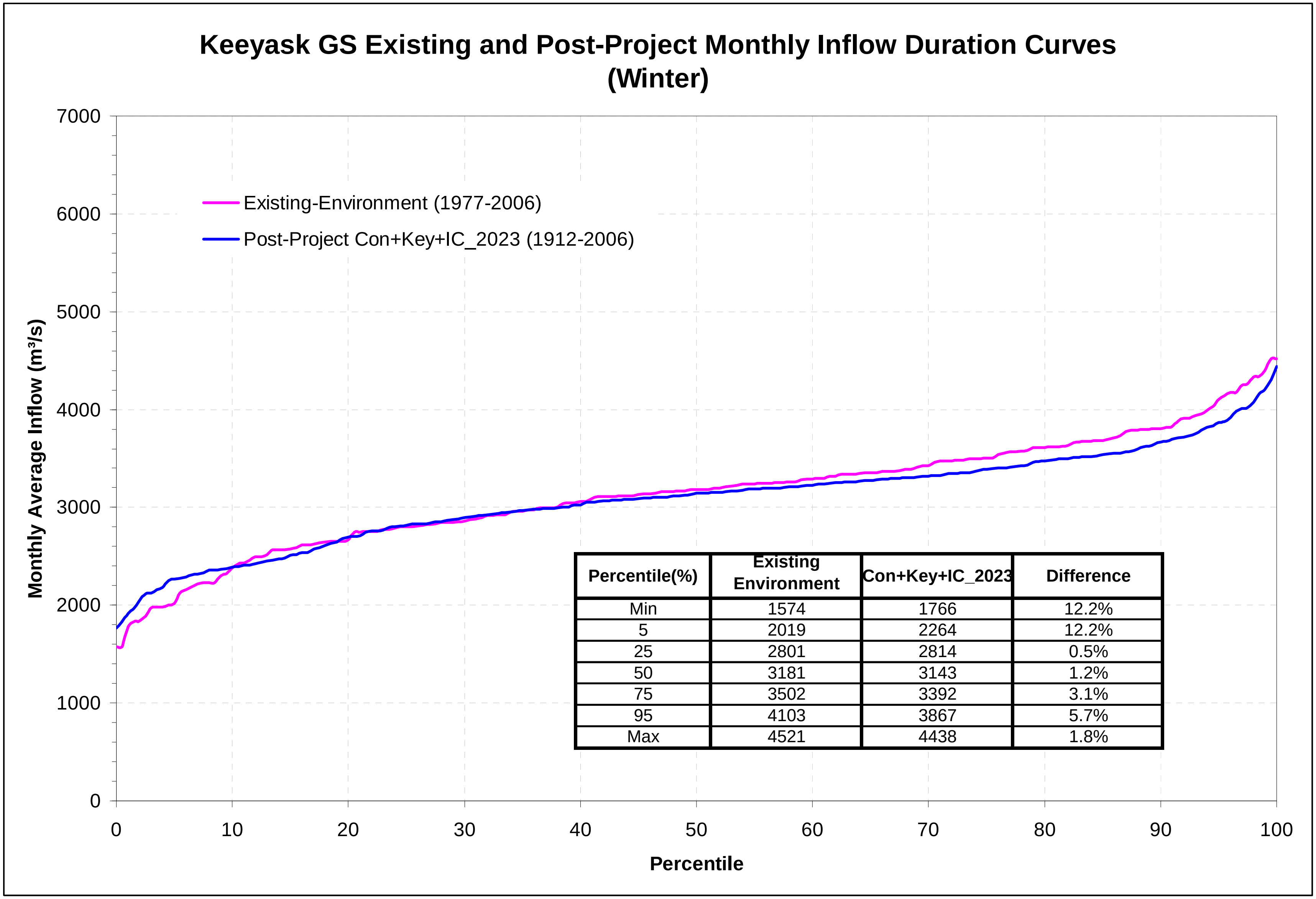

| Percentile(%) | Existing Environment | Con+Key+IC_2023 | Difference |
|---|---|---|---|
| Min | 1401 | 1538 | 9.8% |
| 5 | 1971 | 2041 | 3.6% |
| 25 | 2575 | 2744 | 6.6% |
| 50 | 3064 | 3125 | 2.0% |
| 75 | 3518 | 3470 | 1.4% |
| 95 | 4727 | 4379 | 7.4% |
| Max | 6491 | 6415 | 1.2% |

**Figure 13 Existing and Post-project all-season inflow duration curves comparison**



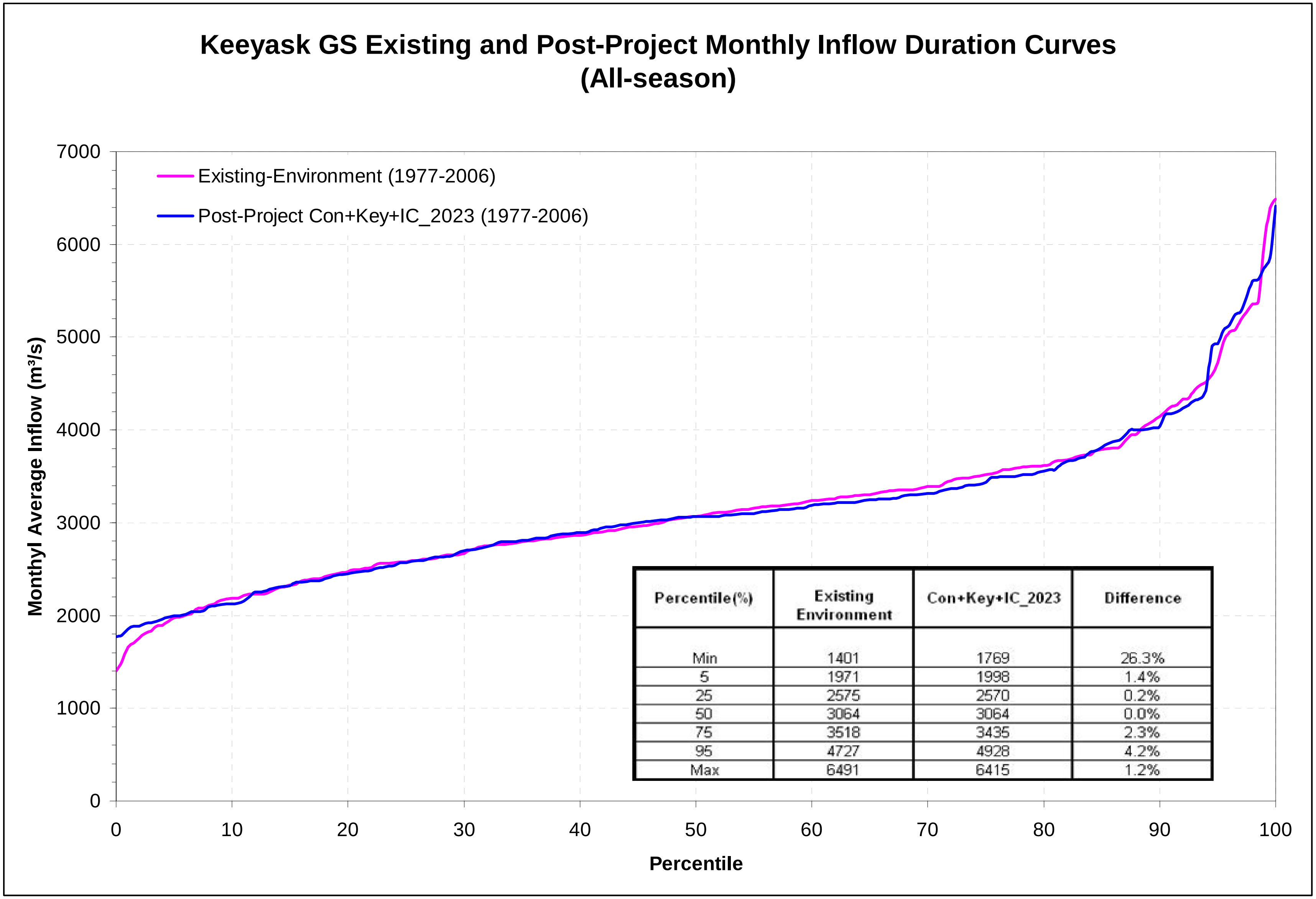

| Percentile(%) | Existing Environment | Con+Key+IC_2023 | Difference |
|---|---|---|---|
| Min | 1401 | 1538 | 9.8% |
| 5 | 1882 | 1949 | 3.5% |
| 25 | 2399 | 2633 | 9.8% |
| 50 | 2866 | 3112 | 8.6% |
| 75 | 3523 | 3696 | 4.9% |
| 95 | 5266 | 5088 | 3.4% |
| Max | 6491 | 6415 | 1.2% |

**Figure 14 Existing and Post-project open water inflow duration curves comparison**




| Percentile(%) | Existing Environment | Con+Key+IC_2023 | Difference |
|---|---|---|---|
| Min | 1574 | 1766 | 12.2% |
| 5 | 2019 | 2264 | 12.2% |
| 25 | 2801 | 2814 | 0.5% |
| 50 | 3181 | 3143 | 1.2% |
| 75 | 3502 | 3392 | 3.1% |
| 95 | 4103 | 3867 | 5.7% |
| Max | 4521 | 4438 | 1.8% |

**Figure 15 Existing and Post-project winter inflow duration curves comparison**




| Percentile(%) | Existing Environment | Con+Key+IC_2023 | Difference |
|---|---|---|---|
| Min | 1401 | 1769 | 26.3% |
| 5 | 1971 | 1998 | 1.4% |
| 25 | 2575 | 2570 | 0.2% |
| 50 | 3064 | 3064 | 0.0% |
| 75 | 3518 | 3435 | 2.3% |
| 95 | 4727 | 4928 | 4.2% |
| Max | 6491 | 6415 | 1.2% |

**Figure 16 Existing and Post-project all-season inflow duration curves comparison**

**Table 1 Post-project inflow data (m³/s) for the Keeyask GS under scenario of Conawapa + Keeyask + IC_2023**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1912** | | | | 3055 | 2955 | 3193 | 3306 | 3212 | 2987 | 3294 | 3308 | 3401 | 3190 |
| **1913** | 3440 | 3312 | 3150 | 3090 | 2966 | 3160 | 3429 | 3404 | 3187 | 3415 | 3427 | 3497 | 3290 |
| **1914** | 3509 | 3282 | 3133 | 2280 | 2350 | 2619 | 3050 | 3176 | 2276 | 2477 | 2757 | 3000 | 2826 |
| **1915** | 3083 | 2903 | 2683 | 2386 | 2769 | 2955 | 2968 | 3020 | 2875 | 2624 | 3055 | 3262 | 2882 |
| **1916** | 3251 | 3097 | 2982 | 3478 | 3798 | 4160 | 4196 | 4202 | 3835 | 4099 | 3809 | 3714 | 3719 |
| **1917** | 3618 | 3186 | 3237 | 3094 | 3000 | 3121 | 3416 | 3436 | 3332 | 3348 | 3484 | 3544 | 3318 |
| **1918** | 3581 | 3416 | 3211 | 2474 | 2794 | 3000 | 3112 | 3205 | 2424 | 2653 | 2890 | 3191 | 2996 |
| **1919** | 3233 | 3051 | 2860 | 2294 | 2317 | 2562 | 3097 | 3150 | 2381 | 2469 | 2744 | 3002 | 2763 |
| **1920** | 3074 | 2853 | 2697 | 2381 | 2605 | 2940 | 3035 | 3140 | 2295 | 2639 | 2839 | 3169 | 2806 |
| **1921** | 3216 | 2988 | 2907 | 2975 | 2828 | 3003 | 3278 | 3384 | 2917 | 3131 | 3309 | 3305 | 3103 |
| **1922** | 3268 | 3226 | 3131 | 2981 | 2957 | 3113 | 3292 | 3127 | 2233 | 2567 | 2847 | 3104 | 2987 |
| **1923** | 3100 | 2957 | 2865 | 2976 | 2801 | 2983 | 3132 | 3106 | 2902 | 3125 | 3308 | 3288 | 3045 |
| **1924** | 3225 | 3155 | 3093 | 2332 | 2325 | 2559 | 3174 | 3242 | 2247 | 2637 | 2575 | 2918 | 2790 |
| **1925** | 3114 | 2878 | 2713 | 3124 | 2906 | 3294 | 3424 | 3399 | 3125 | 3335 | 3392 | 3540 | 3187 |
| **1926** | 3578 | 3399 | 3203 | 2873 | 2803 | 3007 | 3092 | 3147 | 2918 | 3067 | 3258 | 3253 | 3133 |
| **1927** | 3302 | 3234 | 3045 | 4047 | 5060 | 5167 | 5088 | 4318 | 4265 | 4423 | 4016 | 3817 | 4148 |
| **1928** | 3606 | 3327 | 3325 | 3172 | 3010 | 3452 | 3485 | 3296 | 2992 | 3289 | 3296 | 3400 | 3304 |
| **1929** | 3406 | 3284 | 3149 | 1964 | 2045 | 2373 | 2622 | 2715 | 1992 | 2112 | 2417 | 2760 | 2570 |
| **1930** | 2830 | 2692 | 2401 | 2130 | 1998 | 2475 | 2711 | 2751 | 2078 | 2129 | 2407 | 2845 | 2454 |
| **1931** | 2965 | 2588 | 2500 | 2069 | 2030 | 2288 | 2702 | 2672 | 2141 | 2041 | 2361 | 2634 | 2416 |
| **1932** | 2810 | 2665 | 2478 | 2284 | 2344 | 2610 | 3138 | 3126 | 2109 | 2371 | 2421 | 2935 | 2608 |
| **1933** | 3082 | 2849 | 2478 | 2290 | 2330 | 2780 | 3134 | 3179 | 2352 | 2637 | 2927 | 3102 | 2762 |
| **1934** | 3162 | 3006 | 2701 | 3196 | 2980 | 3114 | 3411 | 3385 | 3072 | 3310 | 3364 | 3516 | 3185 |
| **1935** | 3594 | 3343 | 3214 | 2998 | 3063 | 3225 | 3435 | 3386 | 3073 | 3299 | 3392 | 3491 | 3293 |
| **1936** | 3467 | 3286 | 3187 | 2509 | 2640 | 2994 | 2984 | 2755 | 2089 | 2202 | 2426 | 2980 | 2793 |
| **1937** | 3087 | 2832 | 2517 | 2358 | 2169 | 2813 | 2970 | 3004 | 2306 | 2446 | 2761 | 3004 | 2689 |
| **1938** | 3077 | 2930 | 2699 | 2024 | 1961 | 2459 | 2838 | 2516 | 1992 | 2116 | 2374 | 2921 | 2492 |
| **1939** | 3036 | 2793 | 2393 | 1853 | 1892 | 2007 | 2065 | 1913 | 1929 | 2059 | 2359 | 2618 | 2243 |
| **1940** | 2739 | 2512 | 2320 | 1818 | 1690 | 1857 | 1895 | 1898 | 1949 | 1930 | 2264 | 2452 | 2110 |
| **1941** | 2584 | 2453 | 2249 | 1852 | 1538 | 1758 | 1802 | 1787 | 1707 | 1790 | 2162 | 2374 | 2005 |
| **1942** | 2582 | 2342 | 2107 | 2424 | 2305 | 2610 | 3054 | 2887 | 2361 | 2586 | 2759 | 3088 | 2592 |
| **1943** | 3212 | 2931 | 2831 | 2949 | 2867 | 2965 | 3205 | 3016 | 2750 | 2855 | 2973 | 3155 | 2976 |
| **1944** | 3284 | 3126 | 2834 | 2535 | 2566 | 2959 | 2984 | 3024 | 2799 | 3062 | 3193 | 3259 | 2969 |
| **1945** | 3217 | 3091 | 2956 | 3066 | 2973 | 3361 | 3412 | 3392 | 3111 | 3400 | 3552 | 3521 | 3254 |
| **1946** | 3484 | 3190 | 3056 | 2902 | 2815 | 2965 | 3193 | 3345 | 2906 | 3329 | 3299 | 3299 | 3149 |
| **1947** | 3290 | 3247 | 3093 | 3295 | 3371 | 3937 | 3971 | 3589 | 3292 | 3311 | 3480 | 3498 | 3448 |
| **1948** | 3498 | 3303 | 3200 | 3472 | 3661 | 4020 | 4028 | 3089 | 2273 | 2693 | 2911 | 3167 | 3276 |
| **1949** | 3198 | 2988 | 2872 | 2982 | 2806 | 3055 | 3374 | 3480 | 3037 | 3177 | 3322 | 3425 | 3143 |
| **1950** | 3400 | 3374 | 3306 | 3921 | 4758 | 4981 | 5120 | 4313 | 3989 | 4203 | 3971 | 3828 | 4097 |
| **1951** | 3569 | 3236 | 3183 | 3429 | 3844 | 4017 | 4221 | 4031 | 3977 | 3961 | 3737 | 3626 | 3736 |
| **1952** | 3509 | 3351 | 3194 | 2813 | 2513 | 2528 | 3000 | 3073 | 2851 | 3084 | 3011 | 3225 | 3012 |
| **1953** | 3208 | 3104 | 2866 | 3114 | 3248 | 3450 | 3624 | 3579 | 3502 | 3696 | 3580 | 3692 | 3389 |
| **1954** | 3541 | 3344 | 3169 | 3677 | 3958 | 4182 | 4219 | 4228 | 3952 | 4264 | 3758 | 3832 | 3844 |
| **1955** | 3657 | 3510 | 3459 | 4307 | 4989 | 5024 | 4600 | 3457 | 3372 | 3555 | 3470 | 3547 | 3912 |
| **1956** | 3470 | 3323 | 3214 | 3295 | 3461 | 3875 | 3904 | 3262 | 3077 | 3132 | 3273 | 3361 | 3387 |
| **1957** | 3306 | 3120 | 3022 | 2990 | 2841 | 2974 | 3476 | 3334 | 3166 | 3112 | 3114 | 3257 | 3143 |
| **1958** | 3281 | 3143 | 2971 | 2117 | 2288 | 2623 | 3109 | 3049 | 2126 | 2604 | 2523 | 2940 | 2731 |
| **1959** | 3071 | 2761 | 2463 | 3551 | 3872 | 4242 | 4303 | 3937 | 3928 | 3950 | 3942 | 3817 | 3653 |
| **1960** | 3573 | 3347 | 3209 | 2915 | 2834 | 3086 | 3336 | 3141 | 2135 | 2575 | 2586 | 2951 | 2974 |
| **1961** | 3023 | 2808 | 2703 | 1766 | 1744 | 2020 | 1981 | 1938 | 1848 | 1866 | 2238 | 2413 | 2196 |
| **1962** | 2538 | 2331 | 2179 | 3106 | 3067 | 3238 | 3502 | 3355 | 3287 | 3251 | 3289 | 3481 | 3052 |
| **1963** | 3433 | 3260 | 3171 | 3151 | 3049 | 3271 | 3548 | 3054 | 2825 | 2806 | 3149 | 3151 | 3156 |
| **1964** | 3237 | 3080 | 2819 | 2966 | 3050 | 3123 | 3238 | 3316 | 3082 | 3361 | 3386 | 3417 | 3173 |
| **1965** | 3411 | 3352 | 3226 | 4069 | 5479 | 6110 | 5937 | 4338 | 4075 | 4379 | 3776 | 3789 | 4328 |
| **1966** | 3671 | 3509 | 3394 | 4245 | 5344 | 6249 | 6170 | 4531 | 4005 | 4069 | 3711 | 3649 | 4379 |
| **1967** | 3536 | 3381 | 3266 | 3473 | 3478 | 4187 | 3556 | 3112 | 2745 | 2707 | 3027 | 3191 | 3305 |
| **1968** | 3269 | 3121 | 2835 | 3603 | 4090 | 4072 | 4182 | 4155 | 3998 | 4405 | 3874 | 3757 | 3780 |
| **1969** | 3554 | 3320 | 3199 | 4163 | 4292 | 4379 | 4472 | 4530 | 4081 | 4503 | 4438 | 4224 | 4096 |
| **1970** | 3867 | 3516 | 3379 | 4129 | 5088 | 5340 | 5619 | 4083 | 3989 | 4044 | 3998 | 3887 | 4245 |
| **1971** | 3627 | 3349 | 3181 | 3647 | 3882 | 4258 | 4263 | 4123 | 3998 | 4205 | 3718 | 3723 | 3831 |
| **1972** | 3552 | 3315 | 3251 | 4174 | 4585 | 4510 | 3830 | 3211 | 2944 | 3173 | 3196 | 3327 | 3589 |
| **1973** | 3279 | 3068 | 2940 | 3071 | 3091 | 3233 | 3466 | 3488 | 3156 | 3334 | 3316 | 3345 | 3232 |
| **1974** | 3336 | 3199 | 3147 | 4203 | 5743 | 6223 | 6131 | 5801 | 4568 | 4093 | 3873 | 3733 | 4504 |
| **1975** | 3546 | 3350 | 3276 | 4078 | 4370 | 4929 | 4776 | 3843 | 3614 | 3848 | 3714 | 3735 | 3923 |
| **1976** | 3527 | 3337 | 3170 | 2933 | 2971 | 3194 | 2866 | 2145 | 2091 | 2067 | 2412 | 2767 | 2790 |
| **1977** | 2896 | 2481 | 2310 | 2538 | 2579 | 2734 | 3241 | 3285 | 2516 | 2462 | 2616 | 2968 | 2719 |
| **1978** | 3057 | 2830 | 2638 | 3131 | 3069 | 3220 | 3498 | 3489 | 3127 | 3499 | 3513 | 3499 | 3214 |
| **1979** | 3568 | 3410 | 3247 | 4021 | 5274 | 6415 | 5244 | 3227 | 2946 | 2926 | 3155 | 3196 | 3886 |
| **1980** | 3242 | 3069 | 2855 | 1959 | 2105 | 2716 | 3211 | 3015 | 2256 | 2443 | 2398 | 2896 | 2680 |
| **1981** | 3010 | 2760 | 2446 | 2123 | 2087 | 2156 | 2485 | 2570 | 1913 | 2036 | 2365 | 2678 | 2386 |
| **1982** | 2799 | 2570 | 2359 | 3160 | 3287 | 3202 | 3482 | 3307 | 3094 | 3224 | 3272 | 3353 | 3092 |
| **1983** | 3253 | 3120 | 3025 | 3164 | 3369 | 3498 | 3643 | 3252 | 2486 | 2591 | 2829 | 3089 | 3110 |
| **1984** | 3064 | 2920 | 2700 | 2180 | 2358 | 2881 | 3041 | 3212 | 2481 | 2627 | 2868 | 3006 | 2778 |
| **1985** | 3069 | 2921 | 2645 | 3498 | 4018 | 4317 | 4354 | 4264 | 3998 | 4224 | 3694 | 3707 | 3726 |
| **1986** | 3517 | 3253 | 3148 | 4119 | 5380 | 5069 | 3318 | 3378 | 3196 | 3324 | 3370 | 3405 | 3706 |
| **1987** | 3414 | 3245 | 3129 | 2005 | 2105 | 2591 | 2744 | 2119 | 2009 | 1998 | 2316 | 2469 | 2512 |
| **1988** | 2703 | 2395 | 2322 | 1918 | 2042 | 2043 | 1989 | 2050 | 1984 | 1850 | 2127 | 2310 | 2144 |
| **1989** | 2448 | 2293 | 2132 | 1957 | 1938 | 2473 | 2541 | 2569 | 1883 | 2091 | 2376 | 2894 | 2300 |
| **1990** | 2961 | 2636 | 2410 | 2530 | 2797 | 2790 | 2887 | 2353 | 1783 | 1870 | 2315 | 2542 | 2490 |
| **1991** | 2805 | 2412 | 2252 | 2041 | 2369 | 2631 | 3064 | 2720 | 2120 | 2306 | 2264 | 2784 | 2481 |
| **1992** | 2978 | 2724 | 2268 | 2999 | 3041 | 3204 | 3252 | 3302 | 3065 | 3366 | 3316 | 3487 | 3084 |
| **1993** | 3518 | 3302 | 3080 | 2829 | 2579 | 3026 | 3031 | 3035 | 2852 | 2876 | 2820 | 2992 | 2995 |
| **1994** | 3061 | 3143 | 3095 | 2436 | 2637 | 2893 | 3098 | 3065 | 2377 | 2633 | 2814 | 2986 | 2853 |
| **1995** | 3151 | 2907 | 2793 | 2591 | 2584 | 2703 | 3133 | 3076 | 2952 | 2978 | 2998 | 3148 | 2918 |
| **1996** | 3217 | 3079 | 2874 | 3629 | 4928 | 5622 | 5131 | 3998 | 3758 | 3849 | 3498 | 3540 | 3927 |
| **1997** | 3405 | 3188 | 3057 | 3888 | 5175 | 5604 | 5609 | 4282 | 3998 | 4260 | 4005 | 3984 | 4205 |
| **1998** | 3737 | 3435 | 3272 | 3518 | 3664 | 4039 | 4199 | 2794 | 2124 | 2203 | 2462 | 2945 | 3200 |
| **1999** | 2836 | 2511 | 2357 | 2798 | 2859 | 3020 | 3248 | 3067 | 3019 | 3091 | 3318 | 3294 | 2952 |
| **2000** | 3340 | 3260 | 3144 | 3116 | 3426 | 3802 | 3864 | 3890 | 3557 | 3773 | 3548 | 3665 | 3532 |
| **2001** | 3569 | 3399 | 3201 | 3691 | 4902 | 5042 | 5087 | 3562 | 2706 | 2654 | 3058 | 3242 | 3676 |
| **2002** | 3215 | 3069 | 2811 | 3106 | 3110 | 3220 | 3303 | 3311 | 3094 | 2532 | 2613 | 2956 | 3028 |
| **2003** | 3097 | 2875 | 2757 | 1833 | 1769 | 1887 | 1921 | 1907 | 1999 | 1949 | 2273 | 2377 | 2220 |
| **2004** | 2493 | 2245 | 2159 | 3354 | 3938 | 4237 | 4177 | 4169 | 3998 | 4422 | 3876 | 3812 | 3573 |
| **2005** | 3669 | 3383 | 3189 | 4342 | 5425 | 5740 | 5703 | 5856 | 5796 | 4445 | 4177 | 4011 | 4645 |
| **2006** | 3830 | 3616 | 3515 | | | | | | | | | | 3654 |
| **Mean** | 3252 | 3054 | 2892 | 2972 | 3181 | 3458 | 3558 | 3302 | 2915 | 3045 | 3104 | 3248 | 3165 |
| **Min** | 2448 | 2245 | 2107 | 1766 | 1538 | 1758 | 1802 | 1787 | 1707 | 1790 | 2127 | 2310 | 2005 |
| **Max** | 3867 | 3616 | 3515 | 4342 | 5743 | 6415 | 6170 | 5856 | 5796 | 4503 | 4438 | 4224 | 4645 |

**Table 2 - Existing environment flow data (cms) for the Keeyask GS**

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1977 | | | | | | | | | 2083 | 2236 | 2809 | 2881 | |
| 1978 | 2820 | 2804 | 2997 | 2625 | 2331 | 2231 | 2271 | 2375 | 2455 | 3352 | 3663 | 3625 | 2796 |
| 1979 | 3574 | 3633 | 3586 | 3228 | 4026 | 5266 | 5277 | 4201 | 2574 | 2866 | 3481 | 3364 | 3759 |
| 1980 | 3159 | 3111 | 3316 | 3181 | 2510 | 2077 | 1981 | 2108 | 2494 | 2869 | 3185 | 3169 | 2762 |
| 1981 | 3183 | 3298 | 2959 | 1971 | 2228 | 2007 | 2448 | 2113 | 2293 | 2569 | 3140 | 2995 | 2597 |
| 1982 | 2564 | 2570 | 2461 | 2380 | 3184 | 2474 | 2378 | 2607 | 2964 | 3523 | 3551 | 3484 | 2847 |
| 1983 | 3355 | 3258 | 3119 | 3166 | 3180 | 3041 | 2829 | 2888 | 2914 | 3191 | 3497 | 3286 | 3143 |
| 1984 | 3340 | 3252 | 3319 | 3216 | 2949 | 2914 | 2797 | 2670 | 2599 | 2855 | 3039 | 3245 | 3016 |
| 1985 | 3144 | 3246 | 2918 | 2950 | 3356 | 3104 | 3268 | 2969 | 3049 | 3311 | 3463 | 3569 | 3196 |
| 1986 | 3787 | 3794 | 3677 | 3340 | 4946 | 5191 | 4444 | 3229 | 3134 | 3292 | 3389 | 3686 | 3827 |
| 1987 | 3607 | 3425 | 3365 | 3212 | 3021 | 2420 | 2399 | 2228 | 2344 | 2475 | 2791 | 2873 | 2844 |
| 1988 | 2750 | 2745 | 2575 | 2019 | 2769 | 2176 | 1756 | 1683 | 1700 | 1895 | 2227 | 2303 | 2216 |
| 1989 | 2229 | 2186 | 2122 | 2004 | 2398 | 1882 | 2026 | 2398 | 2605 | 2723 | 2756 | 2861 | 2351 |
| 1990 | 2915 | 2772 | 2569 | 2159 | 2566 | 2550 | 2246 | 2176 | 2437 | 2767 | 2898 | 2826 | 2572 |
| 1991 | 2647 | 2493 | 2325 | 2213 | 2497 | 2136 | 2183 | 2235 | 2190 | 2473 | 2652 | 2590 | 2386 |
| 1992 | 2751 | 2777 | 2616 | 2422 | 2755 | 2595 | 2317 | 2336 | 2507 | 3715 | 3816 | 3353 | 2830 |
| 1993 | 3351 | 3569 | 3280 | 2518 | 2074 | 1656 | 1809 | 2606 | 4097 | 3596 | 2960 | 3478 | 2912 |
| 1994 | 3614 | 3426 | 3107 | 2801 | 3064 | 2594 | 2716 | 2706 | 2655 | 2892 | 3063 | 3088 | 2976 |
| 1995 | 3349 | 3238 | 3134 | 3117 | 3002 | 2837 | 2556 | 2954 | 3103 | 3391 | 3200 | 3111 | 3082 |
| 1996 | 3159 | 3059 | 3049 | 2974 | 3518 | 4657 | 5082 | 4597 | 3291 | 3585 | 3408 | 3729 | 3680 |
| 1997 | 3609 | 3666 | 3777 | 3807 | 4481 | 5381 | 5357 | 4840 | 3731 | 3594 | 3884 | 4029 | 4184 |
| 1998 | 3992 | 3955 | 3710 | 3694 | 3774 | 4063 | 4246 | 3726 | 2882 | 2842 | 2854 | 2829 | 3546 |
| 1999 | 2846 | 2925 | 2654 | 2664 | 2582 | 2775 | 2756 | 2680 | 2784 | 3078 | 3114 | 3162 | 2834 |
| 2000 | 3300 | 3495 | 3391 | 3242 | 3072 | 2801 | 3376 | 3500 | 3617 | 3753 | 3680 | 3540 | 3397 |
| 2001 | 3793 | 3943 | 3804 | 3498 | 4433 | 4727 | 4998 | 4329 | 3605 | 3542 | 3477 | 3378 | 3962 |
| 2002 | 3502 | 3194 | 3000 | 2656 | 2817 | 3092 | 3141 | 3333 | 3276 | 3204 | 3046 | 3247 | 3126 |
| 2003 | 3253 | 2978 | 2844 | 2431 | 2294 | 1941 | 1938 | 1878 | 1499 | 1401 | 1574 | 1828 | 2151 |
| 2004 | 1834 | 1890 | 1980 | 1781 | 2178 | 2929 | 3451 | 3351 | 3300 | 3608 | 3829 | 3618 | 2816 |
| 2005 | 3909 | 4265 | 4103 | 4331 | 5058 | 5804 | 6046 | 6388 | 6491 | 5961 | 4400 | 4143 | 5080 |
| 2006 | 4179 | 4249 | 4340 | 4521 | 5084 | 5183 | 4515 | 4275 | 3392 | 2562 | 2635 | 3289 | 4018 |
| Mean | 3225 | 3214 | 3107 | 2901 | 3177 | 3190 | 3193 | 3082 | 2936 | 3104 | 3183 | 3219 | 3114 |
| Min | 1834 | 1890 | 1980 | 1781 | 2074 | 1656 | 1756 | 1683 | 1499 | 1401 | 1574 | 1828 | 2151 |
| Max | 4179 | 4265 | 4340 | 4521 | 5084 | 5804 | 6046 | 6388 | 6491 | 5961 | 4400 | 4143 | 5080 |