Pilbara Regional Flood Frequency Analysis

Jim Davies
Principal Hydrologist/Managing Direction, JDA Consultant Hydrologists, Subiaco in Perth – Western Australia
E-mail: Jim@jdahydro.com.au

Edwin Yip
Engineering Hydrologist, JDA Consultant Hydrologists, Subiaco in Perth – Western Australia
E-mail: Edwin@jdahydro.com.au

Abstract

The paper reviews the Pilbara Region flood frequency factors and design discharge equations used for Index-flood method in 1987 version of Engineers Australia Australian Rainfall and Runoff using an up to date dataset and more recent statistical techniques. Updated flood frequency factors and design discharge equations for the Indian Ocean Drainage Division of Western Australia (including the Pilbara) are presented*. Comparisons are made between the design peak discharge from this study and other recent studies.*

1. INTRODUCTION

Australian Rainfall and Runoff ARR87 (Institution of Engineers Australia, 1987) presents regional flood frequency methods for several regions of Western Australia including the Pilbara.

This paper describes the application of the methods of Hosking & Wallis (1997) to up to date runoff data in the north west of Western Australia, namely the Indian Ocean Division.

A more comprehensive description of the study, including use of Bureau of Meteorology (2013) Rainfall Revision is Davies and Yip (2014).

2. LITERATURE REVIEW OF RECENT STUDIES

Flavell (2012) describes an update to the Index-flood method for the Pilbara, Kimberley, Wheatbelt and Goldfield Regions of Western Australia and refers to the large extrapolation of the gauging station flow rating curves and a general underestimation of the measurement of larger flood events. Flavell (2012) further suggests that because many stream gauges in Western Australia are located immediately upstream of bridges for accessibility regions, that this necessarily results in the potential for flood flows to be underestimated. Flavell (2012) concludes that a conservative approach is required when developing a regional flood frequency procedure.

Rahman et al (2012a) applies the Quantile Regresssion Technique (QRT) and the Parameter Regression Technique (PRT) to the Pilbara Region of Western Australia using only 12 catchments. Rahman et al (2012b) describes a revision to Rahman et al (2012a) for the arid and semi-arid region of Western Australia, increasing the total number of catchments to 57, using relaxed selection criteria, and incorporates the entire arid and semi-arid region of Western Australia into a single fixed region.

3. STUDY AREA

The study area of this paper is the 10 river basins of the Indian Ocean Drainage Division (Drainage Division VII) located in the north west of Western Australia. It comprises the coastal part of the Pilbara together with the Gascoyne and part of the Mid-west Region shown on Figure 1.

River basins 701 to 705 are in the Gascoyne Region, while river basins 706 to 710 are in the Pilbara Region. The total study area is around 535,000 km^2, while individual catchment areas of stream gauging stations range from 0.13 to 86,777 km^2.

With respect to rainfall intensity, there are large variations within Drainage Division VII. For example the rainfall intensity of the 2-year ARI and 1hr duration from ARR1987 ranges from around 18 mm/hr in the south to greater than 35 mm/hr in the north of the drainage division.

4. METHODOLOGY

4.1. Annual Maxima Analysis

AM Series:

(i) In general, the flow measurement records with the following Department of Water quality codes were excluded from the AM series:
   - 5: Estimated Record (Water Level) – Fair
   - 6: Estimated Record (Water Level) – Poor
   - 10: Estimated Record (Water Level)–Not reviewed / Quality not known

(ii) Data for a year were discarded if there was a long period of missing or low-quality data. There are a few exceptions where such data was included if the annual peak flow appeared to be represent a peak for the year.

(iii) The data in AM series was reviewed to ensure no two sequent data are due to the same storm event.

Selected Stations:

(i) The record length of the AM series was a minimum of 10 years after discarding disqualified data.

(ii) The stream gauging stations were not located in an over-flow channel: 57 out of 90 stations were selected after this step.

Hosking & Wallis (1997) reject the possibility of performing regional flood frequency analysis with the entire set of sites being treated as a single region because the theory and practice of hydrology implies that the frequency distribution is likely to depend on the drainage area of the basin. Regional flood frequency analysis should therefore be applied only to regions whose basins cover a fairly small range of drainage area.

Stations were divided into 3 hydrological regions by their catchment area as follows:

- Small Catchment Area Region: Smaller than or equal to 1,000 km^2 (16 stations);
- Medium Catchment Area Region: Larger than 1,000 km^2 but smaller than or equal to 10,000 km^2 (25 stations);
- Large Catchment Area Region: Larger than 10,000 km^2 (16 stations).

In each of the 3 hydrological regions, statistical homogeneity (based on weighted L-moments) was tested to sub-divide the stations into sub-regions. H-Statistic smaller than 2.0 were adopted to be the criterion to form a sub-region, with their own appropriate frequency distribution. For each sub-region, discordance (based on L-moment ratios) was tested.

For each sub-region the appropriate frequency distribution was determined utilizing the Z-Statistic based on weighted L-moment ratios from the following candidate distributions: Generalized Logistic, Generalized Extreme Value, Generalized Normal, Pearson Type III, and Generalized Pareto. The candidate frequency distribution with the smallest absolute value of Z-Statistic was adopted to be the appropriate frequency distribution. After the above steps, a total of 9 sub-regions were identified, see Table 1.

Parameters of frequency distributions were estimated using Method of L-moments. Design discharge (Q_Y, Y = 2, 5, 10, 20, 50, 100-year ARI) were estimated for each gauging station in each sub-region.

4.2. Frequency Factors

For each gauging station, design discharge of 5-year ARI (i.e. Q_5) was adopted as the “index-flood”, and the design discharge of each gauging station was made dimensionless by dividing by Q_5, (i.e. Q_Y /

Q_5). For each ARI, the mean of Q_Y / Q_5 was calculated from all gauging stations to be the "Frequency Factors".

4.3. Design Discharge Equation

For each of the 3 hydrological regions, catchment and climate factors were selected as follows:

- Catchment Area, ***A*** [km^2];
- Average annual rainfall over the catchment area between year 1946 to year 2005 from BoM, ***P*** [mm/year];
- Design Rainfall Intensity [mm/hr] of 2 and 50-year ARI (1hr, 12hrs, 72hrs) from ARR (1987), $I_{hr,ARI}$.

For each hydrological region, a design discharge equation was developed using Stepwise Variable Selection and Multiple Variables Linear Least Square Regression to estimate Q_5 in gauged catchments and ungauged catchments.

5. RESULTS

Small Catchment Area Region (smaller than or equal to 1,000 km^2)

$$Q_5 = 7.32 * 10^{-8} A^{0.651} I_{1hr,2yrs}^{5.251} \quad (1)$$

Medium Catchment Area Region (larger than 1,000 km^2, but smaller than or equal to 10,000 km^2)

$$Q_5 = 2.72 * 10^{-7} A^{0.797} I_{1hr,\ 50yrs}^{3.506} \quad (2)$$

Large Catchment Area Region (larger than 10,000 km^2)

$$Q_5 = 4.26 * 10^{-6} A^{0.783} I_{1hr,\ 50yrs}^{2.815} \quad (3)$$

One set of Frequency Factors for all Area Regions was obtained in this study as follows:

ARI (yrs)	2	5	10	20	50	100
Frequency Factor	0.31	1.00	1.70	2.58	4.15	5.82

The exponents on catchment area (0.651 to 0.797) are intuitively reasonable and consistent with published values from many studies worldwide. However the exponents on rainfall intensity (2.815 to 5.251) are higher than expected. The range of 1hr 2-year ARI intensity varies by a factor approximately 2 over the study area. An exponent of 5.251 suggests the 5-year ARI flood could vary by a factor of 38, which seems physically unrealistic. The reasons for the high exponent on rainfall intensity for all 3 regions is being investigated.

Tables 2 to 5 show the average residual error (%) of design discharges over selected stations, between this study and other recent studies. The results show that the performance of this study and Rahman et al (2012a) are similar, although this study has the best performance in terms of average residual error over all ARI in the Small, Medium and Large Catchment Area Regions and All Regions.

6. COMPARISONS WITH OTHER STUDIES

Flavell (2012): In the Gascoyne Region (i.e. River Basin 701 to 705), Flavell (2012) under-estimates the design discharge in all cases. The design discharges from Flavell (2012) are well suited to the discharges in the Pilbara Region (i.e. River Basin 706 to 710), see Figures 2 to 3.

Rahman et al (2012a) – QRT: This method suits the design discharges for some gauging stations quite well even though they were not included in the Rahman et al analysis. The design discharges also suited design discharges quite well for stations with catchment area smaller than 1,000 km^2 and results were acceptable for stations with catchment area between 1,000 km^2 and 10,000 km^2. However, for catchment areas larger than 10,000 km^2 design discharges were under-estimated in all cases, see Figure 4. It may be because the maximum catchment area of their selected station is only 1,000 km^2.

ARR1987 – IFM: For stations with catchment area smaller than 10,000 km^2, design discharges from ARR1987 were over-estimated for river basin 701 to 708 compared to extreme discharges, see

Figures 2 and 3, but the design discharges suited quite well to design discharge for stations in river basin 709 to 710. For stations with catchment area larger than 10,000 km^2, ARR1987 over-estimated design discharges in all cases if they were compared to design discharges, see Figure 4.

7. CONCLUSIONS

This study reviewed the ARR87 Index-flood method for the Pilbara, using flow measurement records up to 2012. The design discharges were compared to other recent studies, Flavell (2012) and Rahman et al (2012a), and it is found that the design discharges from this study have the best performance over other recent studies.

It is found that design discharges from Flavell (2012) cannot be applied to the Gascoyne Region and the approach to estimate the design discharges is relatively complicated than other similar studies. Flavell (2012) may also mis-represent due to change to measured flow data.

The design discharges from Rahman et al (2012a) are not suitable to apply to catchment area larger than 10,000 km^2, and the method is therefore not applicable to either the Pilbara or the Gascoyne Regions because most catchments in these regions are large. It is unclear whether the design discharge equations from Rahman et al (2012a) should be applied in river basins 702, 703, 705 and 710, because no gauging stations were selected at these river basins in the development of the equations.

The design equations from this study have advantages over other recent studies because they cover the widest spatial distribution and catchment area range, and can be used throughout the Indian Ocean Drainage Division. The design approach of this study is also simple; only catchment area and rainfall intensity from ARR87 are required in the design discharge equations, and it has only one set of frequency factors for three sets of design discharges.

8. REFERENCES

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Table 1. Sub-region Information

Hydrological Region	Sub-Region Name	Selected Stations	H-Statistic	Best-fitted Distribution (Z-Statistic)
Small Catchment Area Region (S)	S-1	701003, 701004, 701005, 701006, 701601, 706207	1.583	Generalized Pareto (-0.323)
	S-2	704001, 707001, 708009, 708227, 710004	0.768	Generalized Pareto (1.537)
	S-3	709002, 709006, 709007, 709009, 709010	1.418	Pearson Type III (0.361)
Medium Catchment Area Region (M)	M-1	703001, 705001, 705002, 707005, 710001, 710204, 710229	0.537	Generalized Pareto (2.776)
	M-2	701007, 701008, 701009, 701010, 701013, 701014, 707002, 707004, 708001, 708011, 708013, 708014, 708016	0.909	Generalized Logistic (-0.072)
	M-3	709001, 709003, 709004, 709005, 709008	-0.069	Pearson Type III (0.673)
Large Catchment Area Region (L)	L-1	701002, 701011, 701012, 702001, 703002	0.532	Pearson Type III (0.104)
	L-2	704139, 704193, 704195, 704196, 706003, 706209, 710003	0.964	Generalized Pareto (-0.327)
	L-3	708002, 708003, 708015, 708223	1.373	Pearson Type III (0.509)

Table 2. Average Residual Error (%) of Design Discharges – Small Catchment Area Region

	2-year ARI	5-year ARI	10-year ARI	20-year ARI	50-year ARI	100-year ARI	*Average*
This Study	64	**51**	**51**	**59**	**77**	**99**	***67***
Flavell (2012)	135	64	67	72	83	105	*88*
Rahman et al (2012a) - QRT	**62**	60	69	82	111	122	*84*
ARR1987 - IFM	1,077	721	833	1,071	1,515	*NA*	*1,043*

Table 3. Average Residual Error (%) of Design Discharges – Medium Catchment Area Region

	2-year ARI	5-year ARI	10-year ARI	20-year ARI	50-year ARI	100-year ARI	*Average*
This Study	62	**41**	**41**	**46**	57	71	***53***
Flavell (2012)	108	65	60	64	75	100	*79*
Rahman et al (2012a) - QRT	**56**	54	54	52	**53**	**56**	*54*
ARR1987 - IFM	1,605	1,058	1,162	1,360	1,641	*NA*	*1,365*

Table 4. Average Residual Error (%) of Design Discharges – Large Catchment Area Region

	2-year ARI	5-year ARI	10-year ARI	20-year ARI	50-year ARI	100-year ARI	*Average*
This Study	156	**49**	**40**	**42**	**54**	**69**	***68***
Flavell (2012)	**73**	70	69	77	105	145	*90*
Rahman et al (2012a) - QRT	112	77	72	68	66	66	*77*
ARR1987 - IFM	2,847	659	740	1,051	1,759	*NA*	*1,411*

Table 5. Average Residual Error (%) of Design Discharges – All Regions

	2-year ARI	5-year ARI	10-year ARI	20-year ARI	50-year ARI	100-year ARI	*Average*
This Study	89	**46**	**44**	**49**	**62**	78	***61***
Flavell (2012)	105	66	65	70	86	114	*84*
Rahman et al (2012a) - QRT	**73**	62	63	65	73	**77**	*69*
ARR1987 - IFM	1,805	851	951	1,192	1,639	*NA*	*1,288*

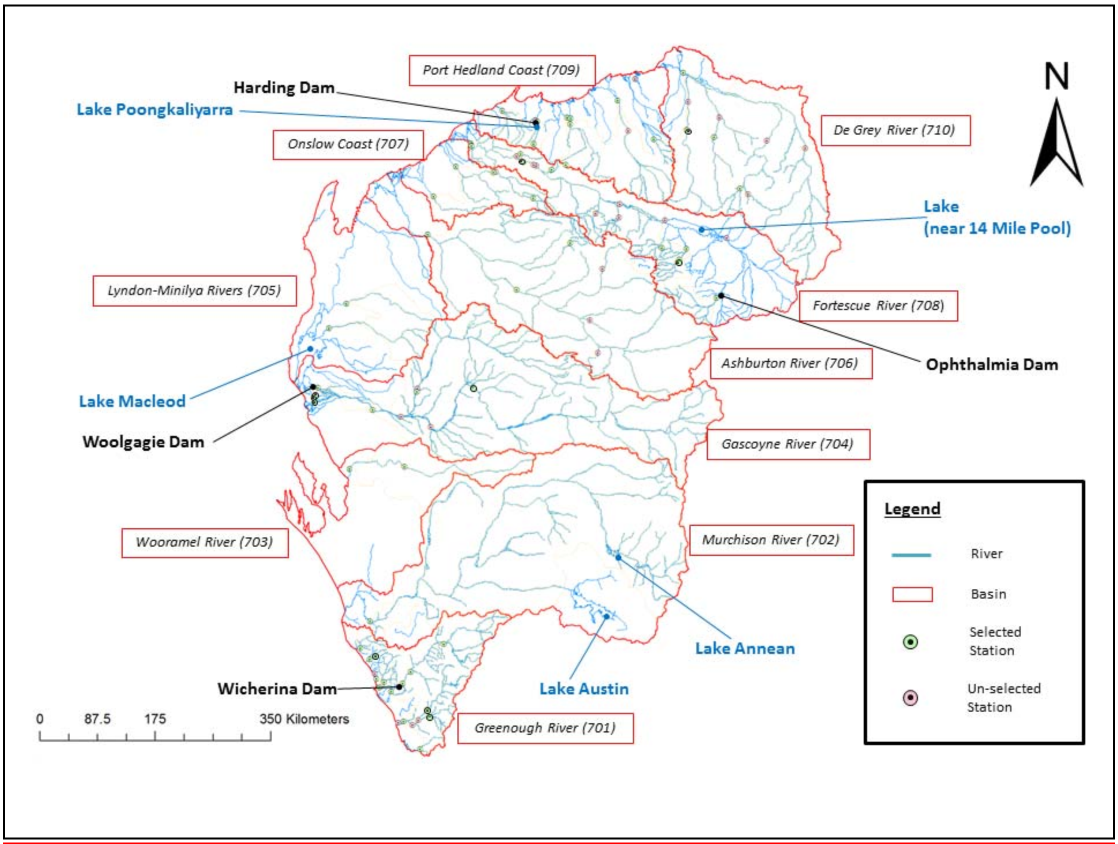

Figure 1 River Basins in Drainage Division VII

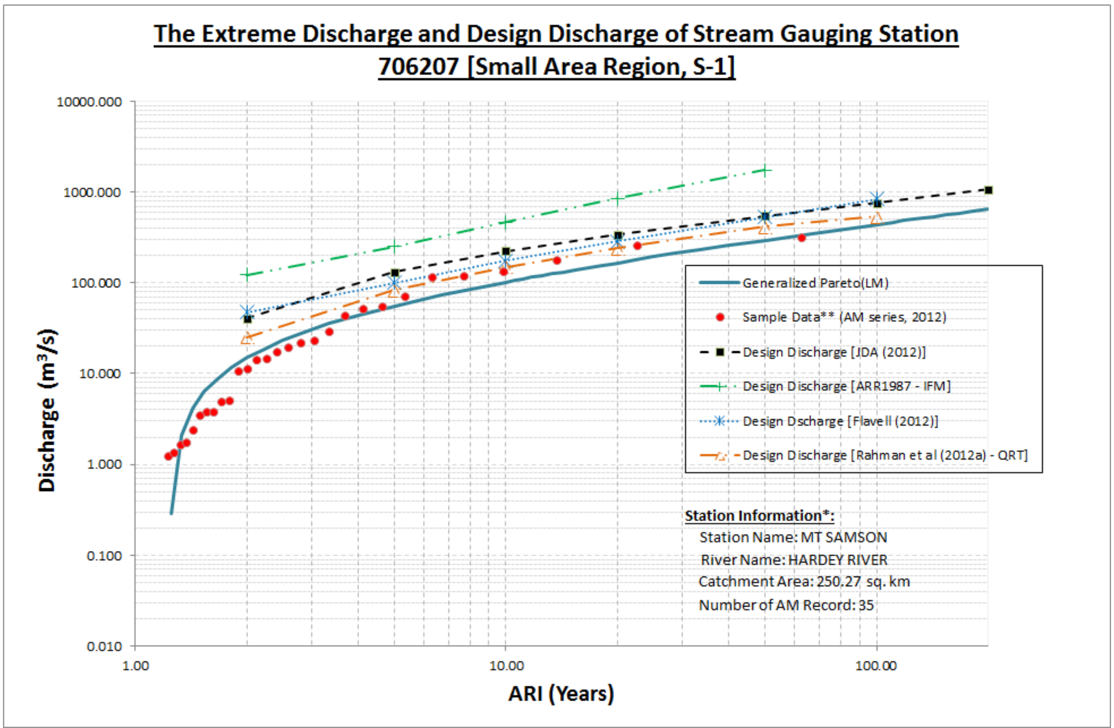

Figure 2 The Extreme Discharge and Design Discharge of Stream Gauging Station 706207 [Example of Small Area Region]

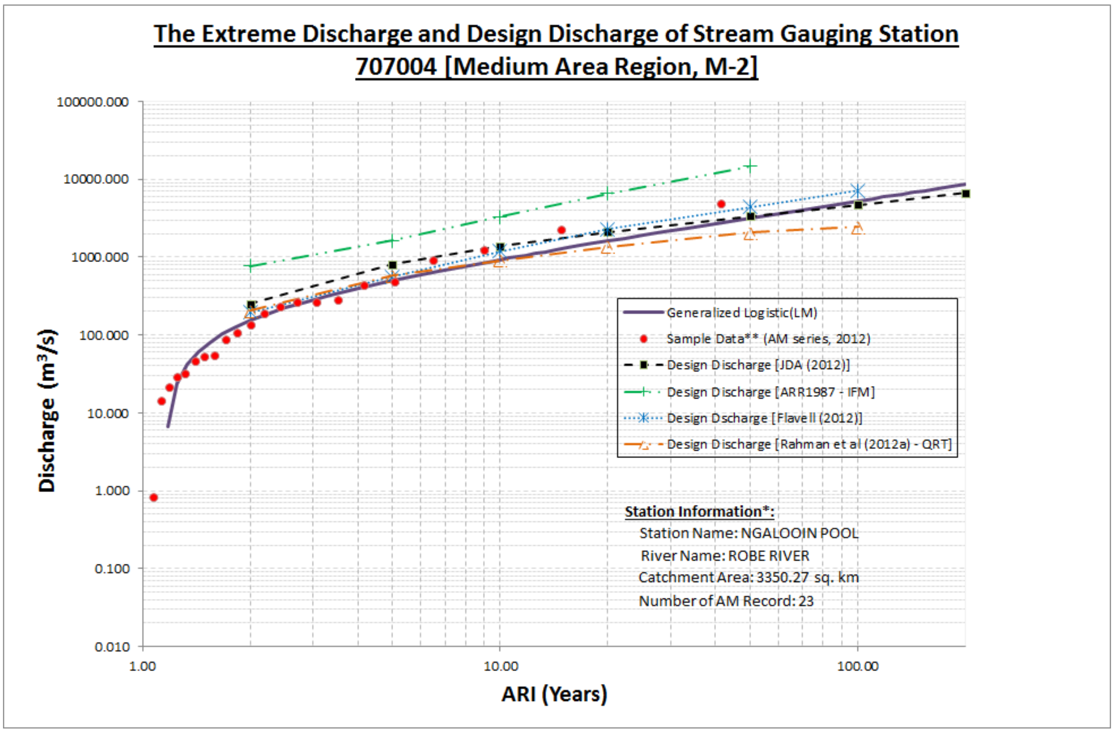

Figure 3 The Extreme Discharge and Design Discharge of Stream Gauging Station 707004 [Example of Medium Area Region]

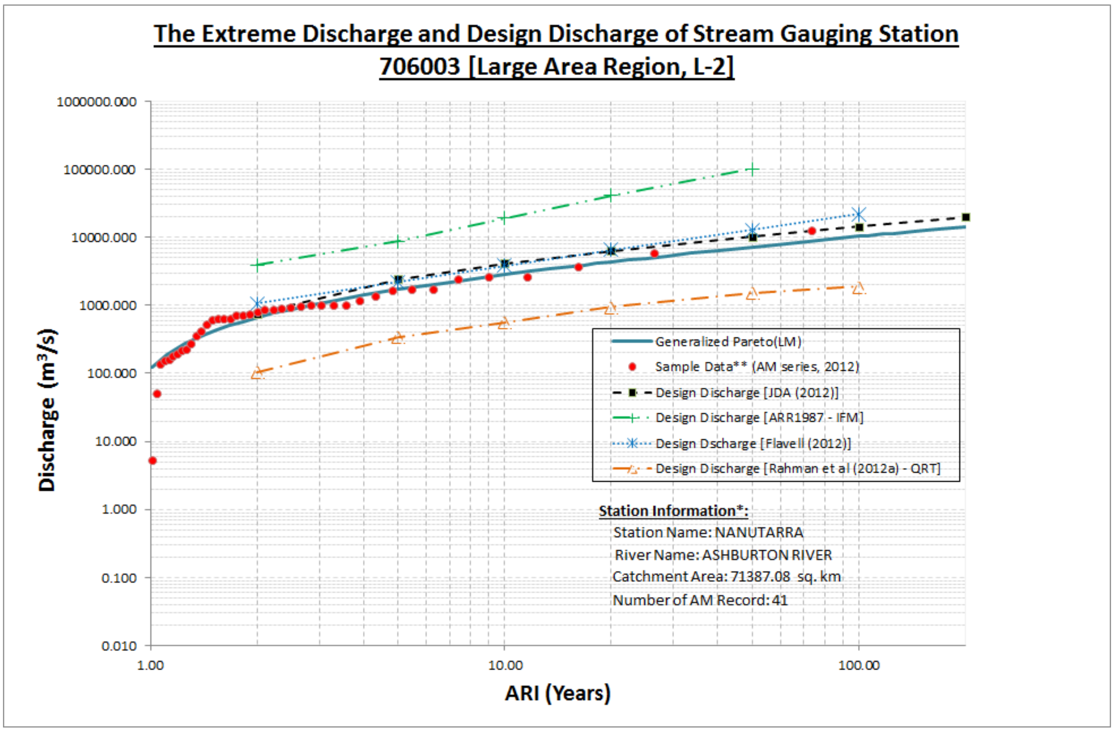

Figure 4 The Extreme Discharge and Design Discharge of Stream Gauging Station 706003 [Example of Large Area Region]