ALS Hydrographics   alluvium   HydroNumerics

River Surveys

Rating table and cross-section review for five pilot sites

Prepared for: The Hydro-Informatics Centre and the Department of Meteorology and Hydrology by Scott Walker, on behalf of the Australian Water Partnership

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Citation
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Table of Contents

1 Introduction 1
2 Site selection 2
2.1 Overview 2
2.2 Pilot site map 3
2.3 The DMH gauging site assessment criteria 4
2.4 Geomorphology 5
System understanding 6
Geomorphic assessment 6
Sagaing gauging station 6
Nyaung Oo gauging location 9
Summary 11
3 Rating review methodology 12
3.1 Overview 12
3.2 The safety of the people 12
Hazard identification 13
Risk assessment and control 14
Take 5s 15
3.3 Embedded capacity building activities 16
Scope 16
Method 16
Schedule 17
Hydrographic surveys 17
Rating curve reviews in the field 18
3.4 Field guide for maintaining hydrological monitoring stations. 19
Indicators 19
4 Rating review activities 20
4.1 Rating review objectives 20
4.2 Data collection 20
Data collection before the field trip 20
Key outcomes of the data collection activities 21

Data collection at the gauging stations 21
Data collected 21
Issues with the data collected 22
5 Statistical significance of differences review of rating curves 23
5.1 Explanation of Method 23
5.2 General aspects of difference testing 24
Characteristic uncertainty of ADCP field gaugings 24
Characterising Rating Table Discharge Uncertainty 25
Sensitivity of rating to channel hydraulics 25
6 Gauging results and assessment 27
6.1 Chindwin River at Kalewa 27
Characterising ADCP gauging uncertainty 27
Characterising DMH Rating table uncertainty 28
Precision and Bias test results 29
Sensitivity of rating to channel hydraulics 31
6.2 Ayeyarwady River at Katha 31
Characterising ADCP gauging uncertainty 31
Characterising DMH Rating table uncertainty 32
Precision and Bias test results 33
Sensitivity of rating to channel hydraulics 35
6.3 Ayeyarwady River at Sagaing 35
Characterising ADCP gauging uncertainty 35
Characterising DMH Rating table uncertainty 36
Precision and Bias test results 37
Test results if the on-site rating curve is used 39
Sensitivity of rating to channel hydraulics 41
6.4 Ayeyarwady River at Nyaung Oo 42
Characterising ADCP gauging uncertainty 42
Characterising DMH Rating table uncertainty 43
Precision and Bias test results 44
Sensitivity of rating to channel hydraulics 46
6.5 Ayeyarwady River at Zalun 46

Characterising ADCP gauging uncertainty 46
Sensitivity of rating to channel hydraulics 50
6.6 Summary of test results 51
7 Rating review results 52
7.1 Chindwin River at Kalewa 52
7.2 Ayeyarwady River at Katha 56
7.3 Ayeyarwady River at Sagaing 60
7.4 Ayeyarwady River at Nyaung 0o 62
7.5 Ayeyarwady River at Zalun 66
Additional hydrographic works to consider for a tidal site 70
8 Conclusions 71
8.1 Summary 71
8.2 History 72
8.3 Gauges and benchmarks 73
8.4 "Loop rating" hysteresis considerations for higher (and tidal) flows 74
8.5 Additional hydrographic works to consider for a tidal site 75
8.6 Data management 76
9 Recommendations 77
Overview 77
9.1 Rationalise flow monitoring stations 78
9.2 Review and upgrade sites in the Lower Ayeyarwady 78
9.3 Review and mentoring of complete data live cycle 78
9.4 Capacity building 78
10 Citations 79
10.1 Rating review references 79
10.2 Geomorphology references 79
10.3 Acknowledgements 79

Figure 1: Chindwin River gauging station at Kalewa

1 Introduction

The Australian Water Partnership engaged ALS-Hydrographics (ALS) with Alluvium Consulting Australia Pty Ltd (Alluvium) and Hydro Numerics Pty Ltd to support the aims of the SOBA and work with the Government of Myanmar's Department of Meteorology and Hydrology (DMH) and Hydro-Informatics Centre (HIC) to select five pilot gauging stations and conduct a review of rating curve information, whilst simultaneously training Directorate of Water resources and Improvement of River systems (DWIR), DMH and HIC staff in surveying, Acoustic Doppler Current Profiler (ADCP) gauging and rating curve reviews.

ALS, Alluvium and Hydronumerics known as the Activity 1 team, recognise the importance of ensuring that the project contributes to the achievement of longer term outcomes for the Government of Myanmar. It is expected that the efforts of the Activity 1 team will contribute to the AWP outcomes of:

- Sight selection for review

The five pilot sites were selected to represent a range of hydrological and geomorphological conditions within the Ayeyarwady River Basin

- Capacity building of key staff

Targeted training of individuals from the HIC, DWIR and DMH through the capacity development of staff in data assessment, field survey techniques, hydrographic techniques including ADCP gauging and reviewing, updating rating curves and most importantly safety training in high risk areas.

- Cross-section reviews

The data gathered from the DMH and the data collected in the field was compared to understand the challenges of a river basin with a high level of geomorphology and the challenges that represents in maintaining the rating curves for water resource management purposes.

- Rating table reviews

Like cross-sections, data gathered from the DMH and the data collected in the field through ADCP gaugings were compared to understand the suitability of the present rating table and to modify the table if discrepancies were discovered

- Recommendations

The efforts of the Activity 1 team aims to support wider river basin planning processes under way in the AIRBM especially Component 2.

This report is to advise the DMH and HIC of the changes of the pilot sites cross-section and related discrepancies for the rating table through the use of Acoustic Doppler Current Profilers (ADCPs) and automatic level survey equipment. It also provides a review of the condition of stream gauges at the pilot sites.

Upon acceptance from DMH of the sites the Activity 1 team set about organising the logistics of the hydrographic survey and rating curve review field trip which was conducted during the second half of February 2017.

2 Site selection

2.1 Overview

A series of meetings were held with relevant government departments in Nap Pyi Taw to identify and select the five pilot sites. The purpose of selecting a diverse set of sites is to ensure that a broad range of results are taken into account during the review process, thus providing a comprehensive report and lessons for a wider program of rating curve reviews.

Criteria for selection of the five sites includes:

- **High expected level of geomorphology.** The Ayeyarwady River and its tributaries are highly active in their geomorphology. The pilot sites are to be of high bed form morphology to ascertain the level of bed dynamics.
- **Representation of the different hydro-ecological zones of the Ayeyarwady basin.** Ensure coverage of the five hydro-ecological zones of the basin to the extent possible
- **DMH sites of interest.** To the extent possible the team will use a selection of the six preferred sites identified by the DHM Director General
- **Importance for informing modelling.** Selection of sites should cover important points for modelling hydrology of the basin below important confluences and a broad coverage
- **Transport and logistics.** Because of time, equipment and travel constraints, it was preferable to select sites within reasonable driving distance from one another
- **Safety.** For the safety of all participants, any sites located in areas not recommended for travel by the Australian Government[1] have been removed from consideration

In addition to the above listed criteria the team also discussed site selection with the representatives from the World Bank and the Integrated Ayeyarwady Delta Strategy to ensure that site selection is coordinated with other hydrographic surveying being undertaken by AIRBM and the IADS.

The five selected sites are shown below in Table 1.

Site No.	Station	River	Location	Hydro-ecological zone
Site 9	Kalewa	Chindwin	23.120182 N - 94.297455 E	Zone 2 – Chindwin
Site 24	Katha	Ayeyarwady	24.182119 N - 96.330583 E	Zone 3 – Middle
Site 28	Sagaing	Ayeyarwady	24.428381 N - 95.393955 E	Zone 3 – Middle
Site 39	Nyaung Oo	Ayeyarwady	21.177252 N - 94.924707 E	Zone 4 – Lower
Site 47	Zalun	Ayeyarwady	17.478974 N - 95.556478 E	Zone 5 – Delta

Table 1: Sites selected for hydrographic survey

[1] Australian Government provides travel advice at http://smartraveller.gov.au/Countries/asia/south-east/pages/myanmar.aspx

2.2 Pilot site map

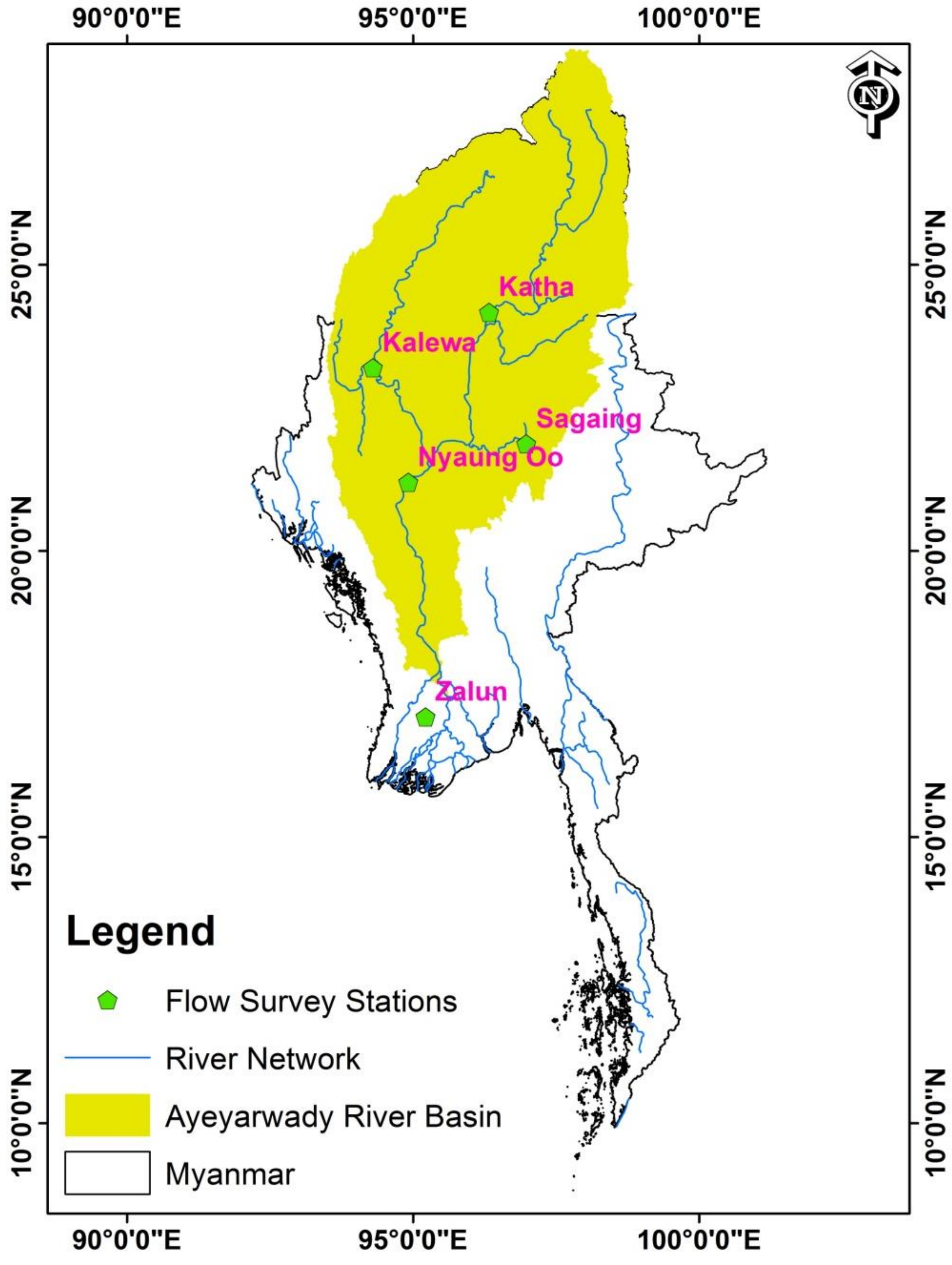


Figure 2: Sites selected for hydrographic survey

2.3 The DMH gauging site assessment criteria

The DMH has 14 criteria to determine the suitability of a gauging site.

A pass requires a score of at least 10 out of 14. Results of testing is shown below in Table 2.

Criteria	Kalewa	Katha	Sagaing	Nyaung Oo	Zalun
The river reach must be stable and fairly straight on both upstream and downstream	Fail – Gauging site immediately u/s of a bend	Pass	Fail – Gauging site is on a bend	Pass	Pass
Elevation and discharge relation should always be uniform i.e. site is not subject to shifting control	Fail	Fail	Fail	Fail	Fail
Site should be sufficiently upstream to the flood forecasting area so that flood warning can be given in advance	Pass	Pass	Pass	Pass	Pass
Site should be easily accessible during all times in a year	Pass	Pass	Pass	Pass	Pass
The site should be sensitive to all stage and discharges, i.e., for a small change in discharge, measurable change in stage should occur	Fail	Fail	Fail	Fail	Fail
Backwater or tidal effect should be the minimum	Pass - Minimal backwater effect	Pass	Pass	Pass	Fail
Site should be away from bridges. It should be upstream > 4 times the width of the bridge as a minimum	Pass (Just)	Pass	Pass	Pass	Pass

When a tributary joins, then the site should be located 0.8 km upstream or downstream of their confluence	Fail	Pass	Pass (Just)	Pass	Pass
At a site, wind action and disturbance due to animals should be the minimum	Pass	Pass	Pass	Pass	Pass
Site should have stable and high banks to contain floods.	Pass	Fail	Pass	Fail	Fail
Rock outcrops and vegetal growth at the reach should be the minimum.	Pass	Pass	Pass	Pass	Pass
Islands should not be present at the gauging section.	Pass	Fail	Pass	Fail	Pass
Cross section of the entire reach of the river should be fairly uniform.	Pass	Fail	Fail	Fail	Fail
Cross currents, vortex and eddies formation, reverse slope in parts of the channel should be absent at the Gauge Discharge site	Pass	Pass	Pass	Pass	Pass
OVERALL	PASS 10/14	FAIL 9/14	PASS 10/14	FAIL 9/14	FAIL 9/14

Table 2: DMH Gauging station suitability results

By the DMH's own selection criteria Katha, Nyaung Oo and Zalun fail their own suitability test. This did not auger well for stable cross-sections and reliable rating tables.

2.4 Geomorphology

Alluvium River Geomorphologist, Misko Ivezich assisted ALS-Hydrographics Senior Hydrographers, Scott Walker and Jacob Ribbons in the review of rating curves on the Ayeyarwady River. Specifically, this includes higher level geomorphic assessments of the river at two specific stream gauging locations studied in detail:

1. The Sagaing gauging station
2. The Nyaung Oo gauging station

Geomorphic processes can significantly impact stage -discharge relationships in alluvial rivers. Typically, in alluvial rivers the hydraulic control is provided by a downstream control. This could include a bedrock outcrop, the roughness and morphology in a downstream reach, bridge abutments or inflow from a tributary downstream.

A purely alluvial river can adjust its cross-sectional area both laterally and vertically. As a result, the hydraulic control downstream can vary, which can change the stage discharge relationship at a point of interest.

This assessment will evaluate historic and contemporary geomorphic processes at each site to determine potential temporal variations in stage -discharge relationships. Fenton and Keller (2001) identified several factors affecting the stage discharge relationship in time, factors called shifting controls. These include changes to the channel morphology and roughness due to erosion, deposition, sediment transport and vegetation.

System understanding

The Ayeyarwady River is the major river basin in Myanmar with a total catchment area of 446,556 km^2. The Ayeyarwady River has high intra-annual flow variability characterised by sustained seasonal floods from monsoon and tropical storm rainfall. For example, at the Sagaing gauging site from July to October water level is typically 5 - 6 m above the flow height between December and April. This is an increase in discharge of approximately 700 % between the high flow period and the low flow period.

The Ayeyarwady River has low flood variability with limited long term changes in seasonal characteristics. This is highlighted by the 25 year ARI flood only being 45 % larger than the 1.5 year ARI flood on the upper Ayeyarwady River (Brakenridge, G. et. al., 2017).

Both the Sagaing and Nyaung Oo gauging stations are located on a 160 km section of the Ayeyarwady River. The Chindwin River, the largest tributary, also merges with the Ayeyarwady River between the two gauging stations. Through this section the river consists of alternating sections of single thread and anabranching reaches. The river typically has an active floodplain/migration zone which is between 5 and 15 km wide.

Analysis of historical imagery between 1986 and 2016 indicates the river transports very high sand loads. Large depositional units within the main channel (i.e. bars and islands) are periodically formed and mobilised over short timeframes. These processes result in high rates of lateral adjustment of the river within the migration zone.

Geomorphic assessment

Sagaing gauging station

The Sagaing gauging station is located on the single thread section of river in Sagaing. The station is located between two large bridges that traverse the river. Upstream of the gauging station the river has an anabranching planform (see Figure 3).

The migration of the river at the gauging station is restricted by a bedrock ridgeline which runs north-south. The ridgeline controls the alignment of the river and limits significant migration of the channel to the north. During a site inspection in February 2017 a significant bedrock outcrop was observed on the left (southern) bank. As result, there is limited capacity for lateral channel adjustment at the Sagaing gauging station.

Analysis of historical aerial imagery of the Ayeyarwady River at the Sagaing gauging station between 1986 and 2016 is presented in Figure 6. There has been minimal change in channel width or alignment at the gauging station location. Downstream of the gauging station there has only been minor adjustment in channel planform. Since 2002 there appears to be some infilling of a downstream side channel. However, this may be a result of the imagery being captured at different times of the year.

Despite the low rates of planform adjustment at the Sagaing gauging station there is still likely to be seasonal variations in the bed morphology due to the high sand loads transported during the high flow period. A comparison of the bed profile between 1996 and 2000 indicates significant bed adjustment with zones of both aggradation and degradation.

The key findings of this assessment and their impacts on the stage - discharge curve are summarised below.

- The stream gauging location is located in an ideal location as there is limited capacity for the channel to adjust its width or alignment.

- The downstream bridge is likely to impact stage under different flow conditions and it is recommended a number of gaugings be taken at higher flows to account for backwater impacts due to the bridge.

- Compared to other locations both upstream and downstream of the site the downstream reach experiences low rates of planform adjustment. As a result, it is unlikely there will be major temporal variation in river hydraulics at the gauging location.

- The river transports significant sand loads which is likely to result in significant variations in bed form morphology. Bed form morphology in the reach downstream impacts the effective roughness, or friction, in the downstream control reach. As a result, the shifting bed form morphology will have minor impacts on river hydraulics at the gauging location. These variations are likely to occur over short time periods (i.e. sub-yearly). This highlights the need to be continually reviewing stage discharge curves.

Figure 3: The Sagaing gauging station on the Ayeyarwady River

Figure 4: Exposed bedrock on the left (southern) bank of the Ayeyarwady River at the Sagaing gauging station

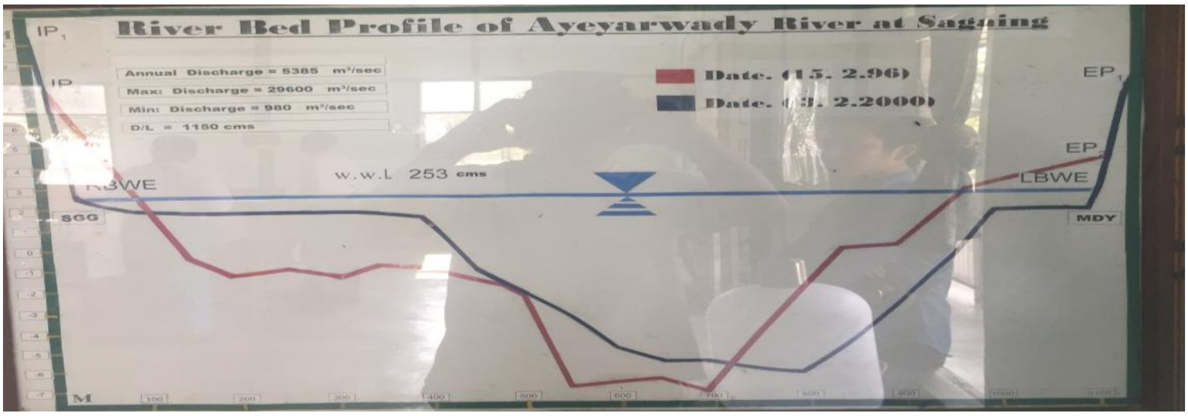


Figure 5: Changes to the cross-sectional area at the Sagaing gauging station between 1996 and 2000

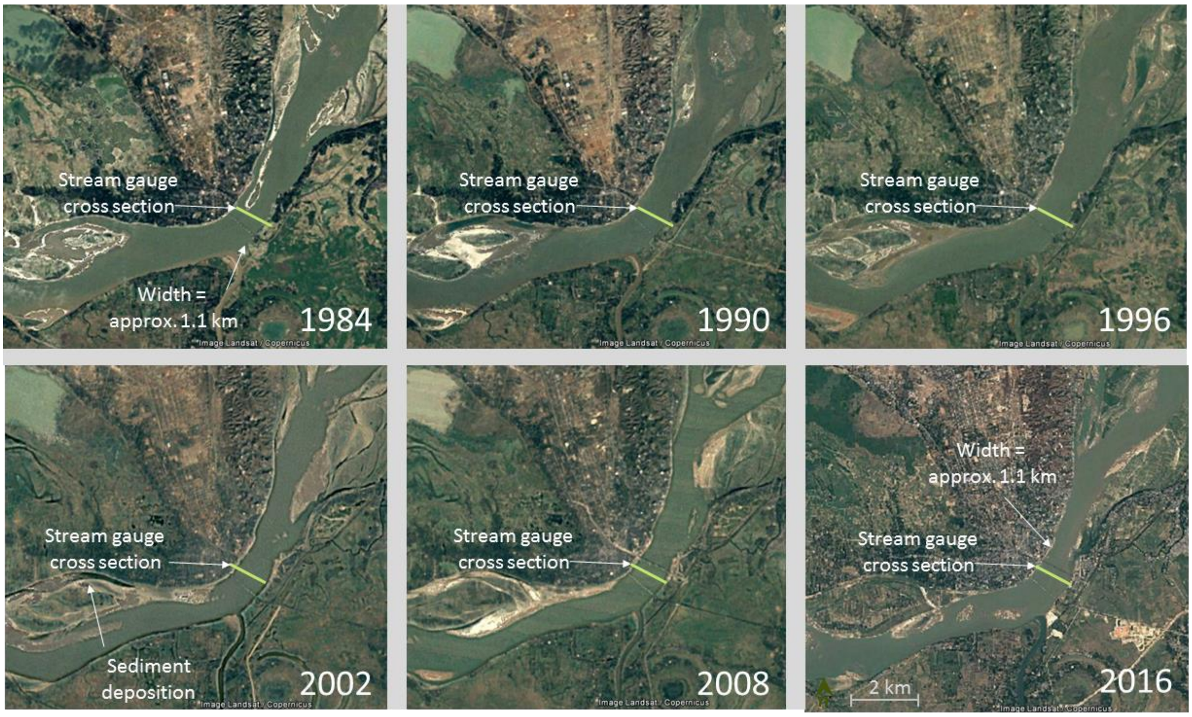


Figure 6. Comparison of historic aerial imagery at the Sagaing stream gauging location

Nyaung Oo gauging location

The Nyaung Oo gauging station is located on an anabranching section of river. The gauging location currently traverses two channels which are separated by an island which is up to 2 km wide

The northern channel abuts sandy floodplain material which would be easily mobilised in high flow events (Figure 8). The southern channel abuts a more resistant, indurated sandy terrace material (Figure 9). During a site inspection in February 2017 a bedrock outcrop was observed on the left bank within the terrace material. The islands primarily consist of silty sand. Vegetation coverage on the island primarily consists of grass.

Analysis of historical aerial imagery of the Ayeyarwady River at the Nyaung Oo station between 1986 and 2016 is presented in Figure 10. In 1986 there was only one primary channel at the gauging location. Since 1986 the northern bank has progressively migrated to the north resulting in a widening of the active channel zone. As a result of the widening there has been significant sediment accumulation and the formation of a large mid channel island which separates the two current channels. As a result, there is likely to have been significant variations in channel morphology and flow characteristics at this site since 1986.

In the downstream anabranching section there appears to have been some deposition and channel contraction in the period since 1986. This would result in increased backwater effects at the gauging location. A flow producing a certain stage may now to be lower than the flow producing the same stage in 1986 due to the downstream channel contraction.

The key findings of this assessment and their impacts on the stage - discharge curve are summarised below.

- The stream gauging station is in a poor location as there is significant capacity for channel adjustment as has been observed since 1986. The channel adjustment is likely to result in major changes to cross-sectional area and flow characteristics.
- The downstream reach is also actively migrating and there is likely to be significant variations in bed form morphology which is likely to have a significant impact on river hydraulics at the gauging station.
- If this location is to be maintained as a gauging station it will need to be regularly reviewed to ensure accuracy of gauging estimates.

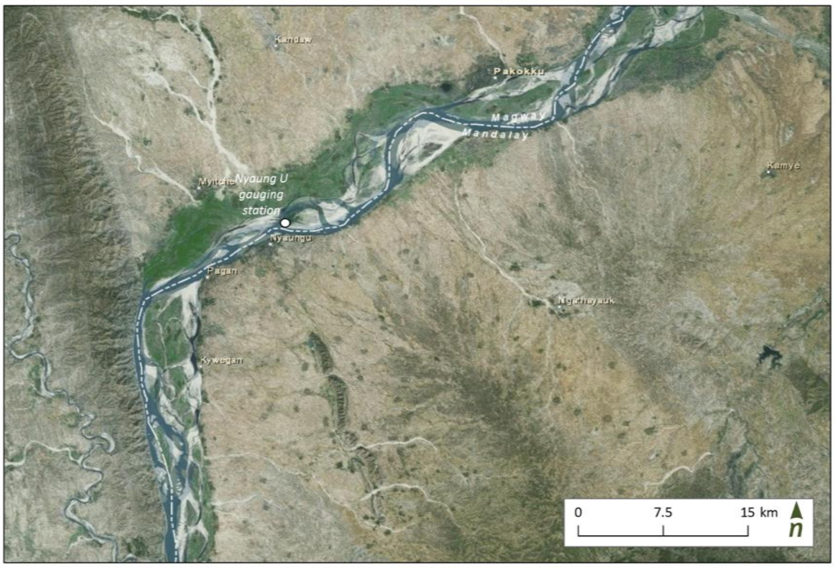


Figure 7: The Nyaung Oo gauging station on the Ayeyarwady River

Figure 8: Right bank of the northern channel at Nyaung Oo consists of highly mobile sandy material

Figure 9: Left bank of the southern channel at the Nyaung Oo consists of indurated sand material

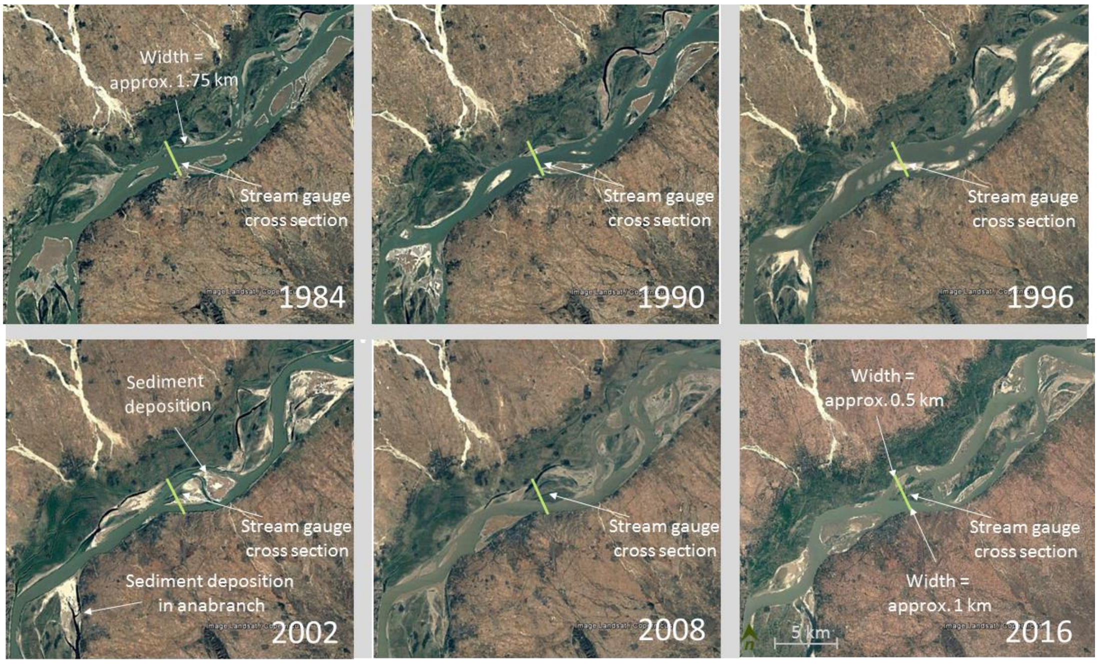


Figure 10: Comparison of historic aerial imagery at the Nyaung Oo gauging location

Summary

Stream gauging in a large mobile alluvial river system like the Ayeyarwady River presents several challenges. Each year during the high flow season significant energy is exerted on the channel bed and banks resulting in large volumes of sediment mobilisation and channel adjustment. As a result, the cross-section area and downstream hydraulic controls are often constantly adjusting causing difficulties in establishing a reliable rating curve for the monitoring site.

To increase the confidence in long term stream gauging estimates in the Ayeyarwady River it is recommended that:

1. The location of existing gauging stations be reviewed considering the geomorphic processes within the river to identify improved locations which have a reduced likelihood of channel change at both the gauging location and within the downstream control reach.

2. Regularly review stage - discharge relationships to account for the temporal variations in channel and bed form morphology.

Figure 11: Surveying the left bank of channel 1 for cross-section review

3 Rating review methodology

3.1 Overview

To combine rating reviews with staff capacity building the first item is to assess not the pilot sites but the skills and knowledge levels of the training participants. Safety was at the forefront of any logistic and training considerations. There would first be a hazard identification and control process with a safe work method statement developed for all participants as a priority. Only once safety assessments and controls were in place would the team travel to the sites and conduct the following:

- Meet the staff officer at each site and discuss the site's history, characteristics, gauging location and benchmark information
- Engage a boat and driver and undertake ADCP gaugings
- Survey the river banks to extend the cross-section information gathered by the ADCP to the flood plain
- Survey and check the benchmarks and piles
- Review the ratings in the field and derive the deviation from the curve, then assess the quality of the gauging
- Collate the data
- Enter the data into a hydrometric data management system for reviewing purposes
- Desktop audit and review of the data presented to the team from The DMH and the data collected in the field.

3.2 The safety of the people

The duty of care and diligence in Australian law holds that an organisation as well as an individual must exercise their powers and discharge their duties with the degree of care and diligence that a reasonable person would exercise if they were in the same position. It can be stated that a reasonable person would be one that possesses the same level of knowledge and ability. Accordingly, there is no single standard of care and diligence, and a higher standard of care may be expected of those who possess special skills, abilities, training, know-how and/or experience in order to keep subordinates, colleagues, team members, associates and stakeholders as safe as practicably possible. The following is the list of stakeholders that Activity 1 would work with to design safety training for in accordance with the level of knowledge skills and expectations.

Name	Employer	Title	Location
Mr. Scott Walker	ALS-Hydrographics	Activity 1 team leader and trainer	All sites
Mr. Jacob Ribbons	ALS-Hydrographics	ADCP field specialist	All sites
Mr. Misko Ivezich	Alluvium	River Geomorphologist	Sagaing and Nyaung Oo
Mr. Justin Stockley	Xylem/Sontek	ADCP manufacturer representative	Zalun, Kalewa and Katha
Ms. Ni Ni Maung	DWIR	Young Water Professional	All sites

Mr. Wai Toe	HIC	Young Water Professional	All sites
Ms. Shwe Yee Mon Mon	HIC	Junior Researcher	All sites
Ms. Thin Su Naing	HIC	Young Water Professional	Zalun
Mr. Ye Thu Aung	HIC	Junior Researcher	Zalun
Ms. Phyu Thinzar Kyaw	HIC	Junior Researcher	Zalun
Mr. Thet Htoo Naing	DMH	Senior Observer	All sites
Mr. Pai Zin Oo	DMH	Junior Observer	All sites

Table 3: List of participants on the pilot site survey field trip

Hazard identification

As part of the Activity 1 team's adherence to duty of care and diligence principles it behoved that the team identify possible hazards to all participants of the rating review and capacity building activities. A questionnaire was sent to potential participants as to their level of swimming capabilities and what safety precautions are they familiar with in regards to gauging station surveys and discharge measurement activities. From the responses it became evident that some familiarisation and training in water self-rescue techniques would be needed. Below is a typical response…

1) Do you undertake many field trips?
   Yes, I do.
2) If so, where do you go / which stream sites are you familiar with?
   Pazundaung creek site.
3) How familiar are you with stream surveys or gauging the flow?
   Yes, but very little.
4) What is your experience with ADCP equipment?
   No. I don't have any
5) Do you know how to survey using an Automatic Level and Staff?
   No, I don't.
6) Do you have a portable PC or laptop that you could bring along on our training trip?
   Yes, I have.
7) Can you swim?
   No, I can't.

It became evident that several participants could not swim, so it was thought essential that life jackets would be worn during all river survey and gauging activities and that water-rescue technique training would need to be a prerequisite to attend field trips to any of the five pilot sites.

The field trip participants organised the PFDs (Personal Flotation Devices or Life Vests), and the Activity 1 team set about training the cohort in self-rescue techniques in the case of the unlikely event that they unwillingly entered a deep water body during our field trip.

Figure 12: Practising throw rope rescue technique

Figure 13: Confidence building

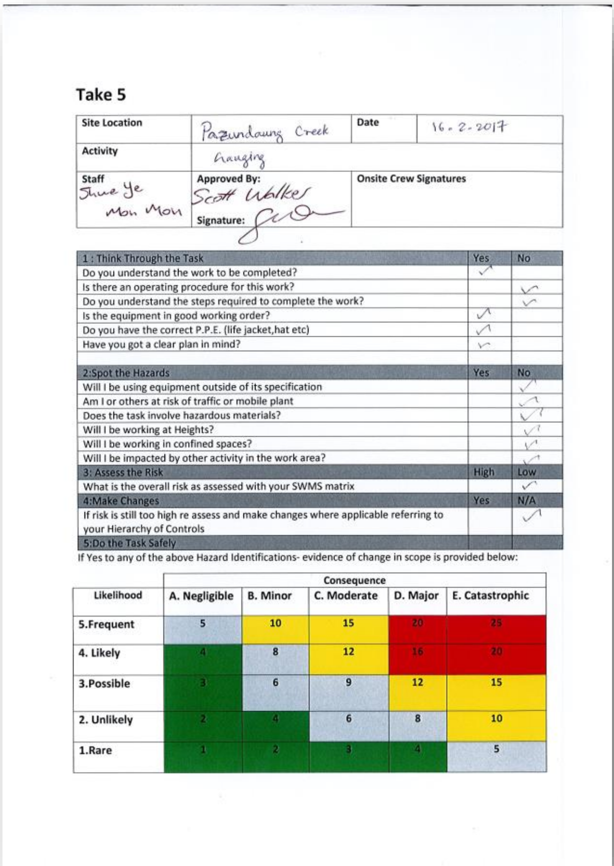
Figure 14: A successful rescue

Risk assessment and control

During discussion with the Observers from the DMH, the Young Water Professionals and Junior Researchers, likely hazards were identified. Then a process of risk assessment was conducted to determine the initial level of risk, required risk control measures, and residual risk remaining after implementation of risk control measures. The results of risk assessments are to be as follows:

- Moving, deep water bodies

- Water-rescue technique training
  - Life jackets and throw bags
  - Working in groups of two or more
- Slippery steep embankments
  - Proper footwear
  - Plan all movements on the river banks
- Unstable boats
  - Training
  - Plan all boat activities
- Hot dry sunny weather
  - Water
  - Hats, sunblock, including thanaka
- Manual handling
  - Plan all manual handling
  - Use two people for heavy lifting



Take 5

Site Location	Pazundaung Creek	Date	16.2.2017
Activity	Gauging		
Staff Shwe Ye Mon Mon	Approved By: Scott Walker Signature:	Onsite Crew Signatures	

1 : Think Through the Task	Yes	No
Do you understand the work to be completed?	✓	
Is there an operating procedure for this work?		✓
Do you understand the steps required to complete the work?		✓
Is the equipment in good working order?	✓	
Do you have the correct P.P.E. (life jacket,hat etc)	✓	
Have you got a clear plan in mind?	✓	
2:Spot the Hazards	**Yes**	**No**
Will I be using equipment outside of its specification		✓
Am I or others at risk of traffic or mobile plant		✓
Does the task involve hazardous materials?		✓
Will I be working at Heights?		✓
Will I be working in confined spaces?		✓
Will I be impacted by other activity in the work area?		✓
3: Assess the Risk	**High**	**Low**
What is the overall risk as assessed with your SWMS matrix		✓
4:Make Changes	**Yes**	**N/A**
If risk is still too high re assess and make changes where applicable referring to your Hierarchy of Controls		✓
5:Do the Task Safely		

If Yes to any of the above Hazard Identifications- evidence of change in scope is provided below:

	Consequence				
Likelihood	A. Negligible	B. Minor	C. Moderate	D. Major	E. Catastrophic
5.Frequent	5	10	15	20	25
4. Likely	4	8	12	16	20
3.Possible	3	6	9	12	15
2. Unlikely	2	4	6	8	10
1.Rare	1	2	3	4	5

Figure 15: 'Take 5' safety form used at the Pazundaung Creek ADCP workshop

Take 5s

The next step in risk reduction is the development of a safety tool known as a take five. This was introduced to all participants before the rating review activities.

A Take 5 risk assessment is a quick safety analysis that is conducted whenever there are hazards identified prior to commencement of any task or activity. The end result of a Take 5 is a Safe Work Method Statement. The method must be developed adhered to for the task at hand by all participants of the task.

A Take 5 review process requires the following steps to be completed:

- Think through all of the tasks involved
- Spot the hazards
- Assess the risks
- Formulate the Safe Work Method Statement (SWMS) if required
- Make the changes and implement the controls as outlined in the SWMS
- Ensure all participants know what is expected of them
- All participants are to undertake the tasks safely as directed in the SWMS

3.3 Embedded capacity building activities

Scope

To assist a broader gauging station review program, DMH have requested a review of approaches for updating rating curves, and demonstration and training using five pilot sites. At the time of the site visit to conduct gaugings, training in the use of Acoustic Doppler Current Profilers (ADCP) was given. During the development of new cross-sections training in the use of automatic level survey equipment was given to the participants whilst gathering information for assessing the existing rating curves and cross-sections.

Method

The Activity 1 hydrographic survey field trip had up to eight participants from the HIC, DWIR and the DMH to be instructed in the use of ADCP and automatic level survey technology at the time of gathering information for the cross-section development and rating review.

The participants had a diverse range of existing exposure and knowledge of the skills required to gauge rivers and develop cross-sections. As such the participants were divided in to groups where the knowledge of the individuals ranged from a working level of knowledge to no knowledge at all.

The purpose of selecting the individuals with the most diverse set of knowledge was to encourage peer learning between the participants. This was deemed to be especially important to ensure exchange of skills and knowledge to the individuals that needed it the most was literally not lost in translation. Tasks and teams were routinely interchanged so at the end of the learning experiences the Activity 1 team would be confident that the individuals had exposure to every facet of what was required to conduct an ADCP gauging, review the results and develop a cross-section for a site.

Individual tasks at the sites includes:

- **ADCP setup** - compass calibration and software
- **ADCP rigging up to boat** - basic knot tying and boat safety
- **ADCP gauging** - selection of gauging sites, review of results against the existing rating and the collection of metadata
- **Checking of gauge posts and piles** – automatic levelling of piles and checking recorded water levels against the CBM derived water level using an automatic level
- **Left and right bank river surveys** – confirmation of which bank is which, bank profiles using automatic levels and various chainage measurement techniques including stadia
- **Safety** - for the safety of team members and training participants, a Take 5 was conducted at every site for the development and implementation of a Safe Work Method Statement

Schedule

The detailed schedule for the hydrographic survey field trip is shown below.

Date	**Activities**
Wednesday 15/02/17	Preparations, gather and check of equipment. Initial safety training including water self-rescue techniques
Thursday 16/02/17	Workshop to test and train in ADCP equipment deployment at the DWIR facility in Yangon with interested parties from HIC, DWIR and DMH (20 participants)
Friday 17/02/17	Drive to Zalun and back to Yangon Three additional Yangon based staff from the HIC attended Stream surveys and capacity building for stream surveying techniques at the **Zalun** stream gauging station
Saturday 18/02/17	Drive to Bagan (10 hrs) - Overnight in Bagan
Sunday 19/02/17	Drive to Kalemyo (12 hrs) - Overnight in Kalemyo
Monday 20/02/17	Stream surveys and capacity building for stream surveying techniques at the **Kalewa** gauging station Drive to Shwebo (11 hrs) - Overnight in Shwebo
Tuesday 21/02/17	Drive to Katha (8 hrs) - Overnight in Katha
Wednesday 22/02/17	Stream surveys and capacity building for stream surveying techniques at the **Katha** stream gauging station Overnight in Katha
Thursday 23/02/17	Drive to Mandalay - Overnight in Mandalay
Friday 24/02/17	Stream surveys and capacity building for stream surveying techniques at the **Sagaing** gauging station Overnight in Mandalay
Saturday 25/02/17	Drive to Nyaung Oo Stream surveys and capacity building for stream surveying techniques at the **Nyaung Oo** gauging station Overnight in Bagan
Sunday 26/02/17	Drive to Yangon via Nay Pyi Taw
Monday 27/02/17	Return equipment and project management tasks

Table 4: Schedule for hydrographic surveys, ADCP gauging and capacity building

Hydrographic surveys

Cross-sections or hydrological surveys were undertaken through a mixture of ADCP and automatic survey levelling equipment. ADCP results in the streams or wetted areas where combined with the surveyed banks using typical topographical survey equipment and techniques to the expected stream maxima for rating review and extrapolation purposes.

Planned surveys were taken at the existing cross-section locations (if known) to not only assist with the review of any existing rating curves, but also to ascertain the amount of cross-sectional change over time in dynamic geomorphological area. Locations were identified through consultation with DMH staff, survey reference marks, benchmarks, maps and plans.

Simple topographic levelling and stadia survey techniques for the banks were used and linked to the datum directed by the DMH. Automatic levels, legs, staff and staff level indicators were borrowed by from DWIR. Training of the staff in their use was conducted concurrently with the ADCP gaugings.

For rating reviews, it is desirable to determine the cease-to-flow level (CTF) of the controlling feature of the stream site in review. This will not be possible on a river as big as the Ayeyarwady. Records and anecdotal evidence from the staff officers indicated that the river never stops flowing so it is virtually impossible to find the CTF of the channel control at the gauging site.

Long-sections to ascertain bed slope and multiple cross sections of channels with the ADCP to determine the profile of the channel in the gauging station reach to assist in the mathematical rating formula reviews were not possible so this information was not recorded. This meant the rating reviews would use a modified version of the Mannings equation to review the ratings.

Rating curve reviews in the field

Ideally, when a change in the stage-discharge relation occurs the rating curve is updated by obtaining new stage and discharge measurements over a range of flow levels over time. Only a small number of measurements were obtained and compared to the existing rating curve.

The basis of the rating curve review method in the field referenced only part of the recognised standards of analysis of discharge by referring to the guidelines in ISO/TS 24154 (2005), ISO/TS 24578 (2012), ISO 748 (2012) and ISO 1100 part 2 (2010).

The percentage deviation is a measure of how far away from the rating curve the gauging result is. The value is not necessarily a measurement of the gauging quality however if the results exceeds as accepted threshold then it can help to determine if the rating is wrong, the gauging is wrong or it is a combination of both.

The percentage deviation is calculated by:

1. plotting the measured discharge (Qm) against the mean GHT on the rating curve
2. determining the discharge (Qr) corresponding to the mean GHT from the existing curve
3. determining the percentage deviation with the following formula:

$$\% \text{ Deviation} = \frac{(Q_m - Q_r) \times 100}{Q_r}$$

Gauging quality is a reflection of the accuracy of the completed gauging; it can be affected by:

- pulsating, turbulent water or low water velocities
- changing stages during the gauging
- faulty equipment
- boat speed too fast

The ability to decide gauging quality combines all the factors associated with the gauging process and this develops with the operator’s experience.

3.4 Field guide for maintaining hydrological monitoring stations.

On the foundation of the capacity building activities, a key deliverable for the pilot survey and hydrographic survey and rating review activities was the field guide to the operation and maintenance of hydrometric monitoring stations.

Activity 1 team have prepared this as separate document titled, ***Field Guide: Operation and maintenance of hydrometric monitoring sites.***

Indicators

Success against the AWP outcomes/impacts will be measured by the indicators outlined in Table 5.

AWP Outcome	Indicators
Active sharing of water reform knowledge and cooperation with the Australian water industry	• Eight (8) participants were trained in hydrographic survey techniques (see **Table 1** for details)
Greater capacity of individuals, organisations and industries to lead and implement IWRM reforms	• Twenty (20) agency staff that are actively engaged in on-the-job training in database development and data quality assurance • Qualitative capacity survey of DWIR, HIC and DMH counterparts at close of project
Adoption of effective policies, practices, and tools by key public and private sector actors	• Adoption of improved hydrographic survey and rating curve review techniques by DWIR, DMH and HIC

Table 5: Indicators for measuring the success of Activity 1

4 Rating review activities

4.1 Rating review objectives

The objectives of the rating review was to:

- Gain an improved understanding of the availability and quality of current rating tables for five pilot sites
- Identify the level of geomorphology of the five pilot sites through cross-section surveys
- Gain an understanding of present site, technology and techniques that may have an impact on the quality and status of the ratings of the five pilot sites

The basis of the rating curve review referred to the standards on the analysis of discharge by referring to the guidelines in ISO/TS 24154 (2005), ISO/TS 24578 (2012), ISO 748 (2012) and ISO 1100 part 2 (2010).

The key steps of the processes include:

- Update cross-sections – Comparison of the original cross-sections requires the Activity 1 team to measure the cross-sections at the pilot sites to assess changes including area, depths and bank shapes.
- Collect and compare discharge information to existing rating curves – An analysis of how well the new stage-discharge data fits within the existing rating curve requires several ADCP gaugings at each site.
- Review to the existing rating curves – Based on the analysis of cross-section changes, downstream control changes and plot of new stage and discharge information on existing rating curves
- Assessment of uncertainty – Identify and quantify the uncertainty, when not judged to be negligible, so that users of the rating curves can understand the potential bounds of error (typically a confidence interval half-width at 95% level)

4.2 Data collection

Data collection before the field trip

The HIC Project Management Unit (PMU) was given the task to collect the appropriate data from the DMH. The Activity 1 team requested that not only the most recent cross-section and rating for each site be presented, but also any or previous rating tables and cross-sections, the related metadata and the dates they were developed. The review process would greatly benefit from previous rating tables and cross-sections to ascertain rate of geomorphology. Previous discharge gaugings were also requests so as to assist with the rating reviews. Unfortunately none of the additional information was forthcoming. This limited the scope of the review. The resulting rating reviews would only be able to compare the existing ratings with the discharge gaugings taken during the capacity building portion of the hydrographic survey field trip.

List of the data obtained for the rating review **before** the field trip from all sites:

- Staff Officer contact details
- Latitude and longitude of the site (to minute of arc accuracy)
- Gauge Zero, Station Elevation and Datum
- One rating table

    - Method used to develop - unknown
- One cross-section
    - Method used to develop – unknown

Key outcomes of the data collection activities

This data was entered into the ALS-Hydrgraphics data management and reporting package known as Hydstra.

This was done to not only secure the data given for the review process, but also the reporting package has a suit of programs that can plot, analyse and report on the both the data presented to ALS-Hydrgraphics and ultimately the data that was gathered during the hydrometric survey field trip.

Issues with the data collected were noticed during this stage and clarifications were sought and forthcoming from the DMH. Previous gauging information was requested for the review process but unfortunately was not provided.

Sites were attributed with a site name and number as they were entered into the database. These labels integrated the existing ALS-Hydrgraphics labelling convention with the DMH site numbers

They are as follows:

Site: Number: DMH009	Site Name: Chindwin River @ Kalewa – Sagaing Region
Site: Number: DMH024	Site Name: Ayeyarwady River @ Katha – Sagaing Region
Site: Number: DMH028	Site Name: Ayeyarwady River @ Sagaing – Mandalay Region
Site: Number: DMH039	Site Name: Ayeyarwady River @ Nyaung Oo – Mandalay Region
Site: Number: DMH047	Site Name: Ayeyarwady River @ Zalun – Ayeyarwady Region

Data collection at the gauging stations

The Activity 1 team visited all of the five pilot gauging stations to undertake an assessment of the present river surveying and discharge ratings

The local staff officer was engaged and local issues such as the channel benchmark (CBM), other benchmarks, pile and gauging locations were ascertained along with any other relevant information that could be valuable metadata for the review process.

All of the sites visited had no digital data recording technology. Remnant signs of analogue data recording technology was evident but was not in operation. Stream heights are taken manually 3 or 4 times a day during normal conditions and up to hourly during flood events.

Data collected

List of the data obtained for the rating review **during** the field trip from all sites:

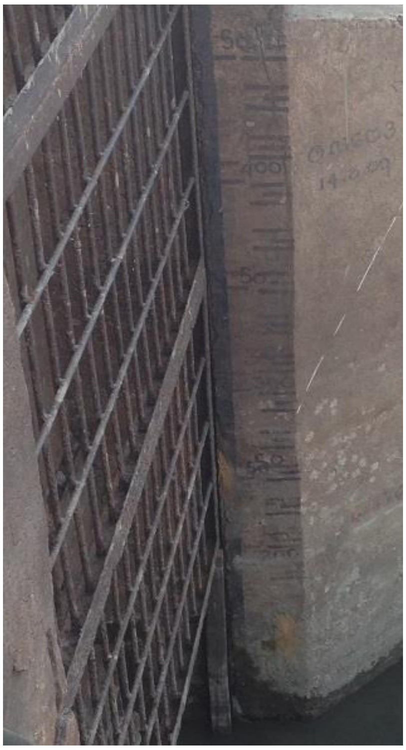
- Stream gauge height
- Gauge Zero and datum confirmation

- Latitude and longitudes (to minute of arc accuracy of 5 decimal points)
    - of the gauging station (piles and gauge posts)
    - of the channel bench mark
    - of the gauging cross-section location
- Flows from ADCP gaugings
- Left and right bank surveys for cross-section reviews
- Discussions with the staff officer to obtain metadata

Issues with the data collected

At the time when the gauging stations were visited, the data collected from the HIC and DMH was verified.

- There was an error found in the latitude and longitude values for Zalun
- It was suspected that the Sagaing rating table was incorrect
- There seemed to be no linkage between the CBM, the zero gauge heights and the datum that was supplied
- Piles and gauges proved to very course and not easily readable and could quite easily be a source of error



Figures 16, 17 & 18: Show how difficult it is to obtain accurate gauge readings

5 Statistical significance of differences review of rating curves

To assess whether the differences observed between the rating tables and the Activity 1 team's gaugings are within the combined measurement uncertainties of the two measurement methods, or if they are statistically significant at the 5% level.

5.1 Explanation of Method

The approach used was developed considering guidelines given in:

- ISO/TS 24154 (2005), Hydrometry — Measuring river velocity and discharge with acoustic Doppler profilers
- ISO 24578 (2012) Hydrometry — Acoustic Doppler profiler — Method and application for measurement of flow in open channels
- ISO 748 (2007), Hydrometry – Measurement of liquid flow in open channels using current meters or floats
- ISO 1100 Part 2 (2010), Hydrometry -- Measurement of liquid flow in open channels -- Part 2: Determination of the stage-discharge relationship

- Of particular relevance is ISO 1100's section 6 on *Methods of checking stage-discharge relationships:*

> *Generally, when a check discharge measurement plots within a small percentage of the rating curve, it is assumed that the rating curve still applies, and no correction is made in the form of either a shift or a new rating curve. The percentage by which a measurement may deviate from the rating curve without applying a correction is usually based on the uncertainty of the discharge measurement. See ISO 748 for a description of computing discharge measurement uncertainty. If, for instance, most discharge measurements are made to 5 % uncertainty, then shifting-control techniques will not be employed unless a check measurement plots further than 5 % from the rating curve.*
>
> *Another approach is to undertake a statistical analysis of the rating curve to define the dispersion (standard deviation) of the measurements around the rating curve. When two or more measurements indicate a deviation of more than two standard deviations from the rating curve, then a shift curve or a new rating curve is defined. Standard deviations are usually defined separately for each segment of a rating curve.*
>
> *A bias check is also performed in some cases to define periods when the rating curve might have shifted, even though check measurements are within the specified uncertainty of discharge measurement or within two standard deviations for the rating curve. For instance, two or more measurements might plot within 5 % of the rating curve, but are all on the same side of the rating curve. Various statistical tests can be used to test for bias.*

To follow the above approach to testing, the characteristic discharge measurement uncertainty of both the Activity 1 team's gaugings and the DMH rating tables needs to be defined for each site.

Note that if the observed differences are within the combined uncertainty of the two discharge measurement methods, then the differences can be accepted, and no change to the rating need be considered.

The student's-t test method was then used to test for bias (degree to which gaugings fall "more on one side of the rating table than on the other"), and the Chi-squared test for degree of scatter around the mean difference observed. The results are tabulated and shown as a plot of expected versus actual differences distributions for each site. Note that this test sheet approach is the same as that recently developed for NSW Office of Water for management of stations with discharge rating tables.

5.2 General aspects of difference testing

Characteristic uncertainty of ADCP field gaugings

Prior to characterising the gaugings uncertainty, the writer here accepts that the experienced ALS-Hydrographics field staff who captured the river gaugings using their ADCP- have followed their work procedures, which are consistent with the ADCP manufacturer's guidelines, as well as with ISO's 24154 and 24578.

Characterising the uncertainty of the ADCP gaugings will require some assumptions to be made due to the fact that the ISO's do not give a calculation method, but state that the Technical Standards committee who wrote the standard are still looking into it.

ADCP sensor manufacturers have come up with an interim method which consists of doubling the standard deviation observed from a group of gaugings taken during steady flow conditions, such as ALS-Hydrographics have done at the 5 DMH sites. Although this is better than nothing, it only shows how internally consistent the set of gaugings are with each other. It is still useful however to calculate it and compare it with the uncertainty from the method explained below, and select the larger of the two as the characteristic uncertainty.

What is missing is either a Type A measurement uncertainty determination (i.e. versus an accurate and independent measurement method), or a Type B "by components" approach.

In the absence of these objective and well researched uncertainty characterisation sources, the decision was made here to equate the ADCP gaugings with current meter gaugings. The reason for doing this is that the current meter gauging method DOES define how to calculate its measurement uncertainty, in objective terms.

The ADCP gaugings have taken many more verticals and many more points per vertical than traditional current meter gaugings. As a conservative "equivalent" a current meter gauging with 25 verticals and 20 points per vertical will be adopted as giving and INDICATIVE ADCP gauging measurement uncertainty. ISO 748 was used to calculate this indicative measurement uncertainty, as below:

If the measurement verticals are placed so that the segment discharges ($b_i\ d_i\ v_i$) are approximately equal and if the component uncertainties are equal from vertical to vertical, then equation [22] simplifies to:

$$u(Q) = \left[u_m^2 + u_s^2 + \left(\tfrac{1}{m}\right)\left(u_b^2 + u_d^2 + u_p^2 + \left(\tfrac{1}{n}\right)\left(u_c^2 + u_e^2\right)\right)\right]^{1/2} \qquad \ldots[23]$$

- Where "u_Q" stands for standard relative (±%) uncertainty of discharge "Q", and -
- u_m- is uncertainty due to limited number of verticals
- u_s- is uncertainty due to variable responsiveness of instruments used to measure depth, width and velocity, taken here as = ±1%
- "m" is number of verticals, here set as 25 to equate to an ADCP gauging

- “n” is number of points per vertical, here set at 20 to equate to an ADCP gauging
- u_b- is uncertainty due to cross section width measurement
- u_d- is uncertainty due to depth measurement
- u_p- is uncertainty due to limited number of points per vertical
- u_c- is uncertainty due to sensor calibration
- u_e- is uncertainty due to limited exposure time

The ISO gives guidelines on how to define each of the above, for current meters. Wherever possible these guidelines were used and adapted to suit ADCP usage. The spreadsheet used to calculate the ADCP gaugings’ uncertainty includes each of the above components, and is used to indicate a characteristic uncertainty for each sites’ set of ADCP gaugings.

Note that these individual site calculations give an indicative ADCP gauging uncertainty of ±4% (see later subsections with detailed calculations). So unless double the standard deviation of the gaugings versus their mean exceeds 4% (see earlier explanation), then ±4% will be accepted as the characteristic uncertainty of the ADCP gaugings.

Characterising Rating Table Discharge Uncertainty

No information was given on how the Rating Tables DMH have provided, were derived. If DMH gaugings had have been provided then each rating table’s uncertainty could have been calculated as described in ISO 1100: *Another approach is to undertake a statistical analysis of the rating curve to define the dispersion (standard deviation) of the measurements around the rating curve*. Given this standard deviation of the differences, the characteristic measurement uncertainty of that section of the rating can be calculated as twice the value of the standard deviation.

However, in the absence of such information, only a generic indicative value can be defined. This definition is based on the general approach to rating definition as being the line of best fit through a group of gaugings taken at different stages. As stated in ISO 1100: *If, for instance, most discharge measurements are made to 5 % uncertainty, then shifting-control techniques will not be employed unless a check measurement plots further than 5 % from the rating curve.* If DMH are using an ADCP to take the gaugings for establishing and checking their rating relationship, then the rating relationship can be deemed to have a discharge uncertainty of no more than ±4%, noting that this is the indicative uncertainty of the individual ADCP gaugings (as explained in section A.3.1).

In summary- ±4% has been adopted as the characteristic uncertainty of the 5 rating tables, on the assumption that they would have been established by fitting them to match DMH field ADCP gaugings.

Sensitivity of rating to channel hydraulics

As noted in ISO 1100: *When testing and checking stage-discharge relationships, it is very important that the analyst understands why the measurements plot as they do. Without this understanding, the analyst might incorrectly apply and interpret certain statistical tests. The analyst should always consider what has been happening to the controlling stream characteristics and make decisions based on hydraulics rather than arbitrarily using statistical results.*

The hydraulic aspect which controls the relation between stage and discharge is either section control (e.g. rock bar or sudden contraction downstream) or channel control. Debris build-up or removal at the section control and/or in the channel bed can increase or decrease the discharge compared with a previously established rating.

When large differences between gaugings and the rating are observed, this suggests the need for consulting people with knowledge of the channel hydraulics and history in the river reaches either side of the site. The starting point should be to identify the date the DMH rating was established. The purpose of such consultation would be to find out if and when changes may have occurred since then, which have affected either bed roughness or water surface slope (backwater effects from some downstream blockages), which could explain any observed significant differences.

As a way of indicating the magnitude of any rating table change in hydraulic terms, Mannings discharge equation was used, to quantify the change in terms of either water surface slope changes or bed roughness changes or a combination of both. The basic Mannings equation for “channel control” is:

$$Q = \frac{AR^{2/3}S^{1/2}}{n}$$

Where “Q” is discharge in cubic metres per second (cumecs); “A” is wetted cross section area in sq.m; “R” is hydraulic radius which = A/P; “P” is wetted perimeter in m; “S” is water surface slope in m/m and “n” is average bed roughness.

The ratio of the square root of slope to the roughness coefficient is called the conveyance factor “K”, such that:

$$Q = KAR^{2/3}$$

This formulation of the Mannings equation can then be used for a particular stage height to estimate the magnitude in changes of slope or roughness coefficient that would be required at the site, to shift the rating from its present position to match the gaugings. This was done for each individual site analysis.

A rating change could also be due to a change in channel control or a change in downstream section control. If it is due to only a channel control change then the rating curve change can be represented as a change in Mannings roughness coefficient. If it is some change in a downstream section control it can be expressed in the change in water surface slope it causes upstream at the monitoring site of interest. In either case the change can be expressed in a change in conveyance factor “K”, which includes both factors. All that is required is a discharge and the geometric properties of the wetted cross section (A & R), such that:

$$K = \frac{Q}{A \times R^{2/3}} = \frac{S^{1/2}}{n}$$

This “K” factor can be calculated for each point on the DHM rating table, and plotted against stage height. The K factor of the ALS-Hydrgraphics gaugings can be calculated in the same way, but using “Q” from the gaugings instead. The K factor rating equivalent to the DHM discharge rating can then be compared with the ALS-Hydrgraphics gaugings “K”, and a change in the K factor rating curve can be postulated to go through the ALS-Hydrgraphics gauging “K” and re-join the DHM K rating at a logical point of return, such that the upper portion of the DHM rating remains unaffected.

Given the postulated new K factor rating curve, it can be used to calculate revised discharge values for the range of stage heights affected by the K-rating change, as $Q = K \times A \times R^{2/3}$.

6 Gauging results and assessment

6.1 Chindwin River at Kalewa

Characterising ADCP gauging uncertainty

All gaugings were assessed to be of a good quality. The uncertainty due to the scatter of ADCP measurements about their mean value was calculated as twice the standard deviation of the set of values, which gave a figure of ±3.6%. The other more objective uncertainty calculation approach was also used to calculate an indicative discharge measurement uncertainty for the set of ADCP gaugings, as listed below:

```
ALS Hydrographics NATIONAL

Site     DMH009          Chindwin @ Kalewa - Sagaing Rgn
VarFrom   100.00         Stream Water Level
VarTo     140.00         Stream Discharge Cumecs
Period  01/10/1999 - 30/09/2018
```

Date	Number	Stage	Flow	Deviation	Area	Velocity	Meth	Temp
10:30_20/02/2017	1.0	2.244	448.791000	-34.93	1470.9680	0.305	AD	24.9
10:36_20/02/2017	2.0	2.244	442.375000	-35.86	1470.3950	0.301	AD	25.2
10:42_20/02/2017	3.0	2.244	449.887000	-34.77	1467.4280	0.307	AD	24.9
10:48_20/02/2017	4.0	2.244	448.710000	-34.94	1463.1300	0.307	AD	25.3
10:58_20/02/2017	5.0	2.244	454.253000	-34.14	1481.1030	0.307	AD	25.1
11:05_20/02/2017	6.0	2.244	442.103000	-35.90	1463.8230	0.302	AD	25.4
11:13_20/02/2017	7.0	2.244	452.104000	-34.45	1473.4080	0.307	AD	25.1
11:50_20/02/2017	8.0	2.244	440.352000	-36.15	1478.3940	0.298	AD	25.4
11:54_20/02/2017	9.0	2.244	464.446000	-32.66	1458.3640	0.318	AD	25.1
12:00_20/02/2017	10.0	2.244	444.230000	-35.59	1444.5670	0.308	AD	25.6
12:06_20/02/2017	11.0	2.244	451.578000	-34.52	1458.8930	0.310	AD	25.1
12:13_20/02/2017	12.0	2.244	457.855000	-33.61	1490.9600	0.307	AD	25.7
12:21_20/02/2017	13.0	2.244	466.098000	-32.42	1466.7230	0.318	AD	25.2

Table 6: February 2017 gauging results from Kalewa with the % deviation from the existing curve

Figure 19: Gauging at Kalewa February 2017

Calculating "u(m)" standard uncertainty due to no. of verticals (ISO 748 Table E.6):-		
Average number of verticals used for set of gauging	**25**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no. of verticals= +/-	**1.76**	%
Assuming a value for "u(s)" for instrument bias factors= +/-	**1**	%
Calculating "u(b)" standard uncertainty of width measurement method (ISO Table E.1):-		
What is the average width of the channel for the set of gaugings?	**302**	m
What is the uncertainty of width measurement in terms of +/- metres=	**0.5**	m
Indicative standard uncertainty of width measurement= +/-	**0.165563**	%
Calculating "u(d)" standard uncertainty of depth measurement method (ISO Table E.2):-		
What is the average depth of the channel for the set of gaugings?	**4.9**	m
What is the uncertainty of depth measurement in terms of +/- metres=	**0.01**	m
Indicative standard uncertainty of depth measurement= +/-	**0.20568**	%
Calculating "u(p)" standard uncertainty due to points per vertical (ISO Table E.4):-		
Average number of points per vertical for set of gaugings=	**20**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no points per vertical= +/-	**0.56**	%
Calculating "u(c)" standard uncertainty due to velocity sensor calibration limitations (ISO Table E.5):-		
Average velocity (approximately) for set of gaugings=	**0.307**	m/s
Indicative standard uncertainty due to velocity sensor calibration= +/-	**1.09**	%
Calculating "u(e)" standard uncertainty due to limited exposure time (ISO Table E.3):-		
Average exposure time per point in each vertical, for the set of gaugings?	**0.5**	minutes
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited exposure time= +/-	**6.15**	%
Calculating indicative discharge uncertainty:-		
Standard Uncertainty= +/-	**2.048**	%
Expanded uncertainty at 95%ile=+/-	**4.0**	**%**

Table 7: Chindwin River at Kalewa uncertainty

As this ±4.0% result is larger than the ±3.6% calculated earlier (from the variability of the gauged flows to their mean), then ±4.0% will be adopted here as the characteristic discharge measurement uncertainty of the ADCP gaugings.

Characterising DMH Rating table uncertainty

The figure of ±4.0% was adopted as a realistic match to DMH's own ADCP gaugings- noting that the best fit line (rating) through the gaugings should actually be better than this.

Precision and Bias test results

Thirteen (13) ADCP gaugings were taken over a 2 hour period, during a steady flow regime, with stage (or gauge height) remaining at 2.244m throughout the period. This identified an average discharge of 451.0 m^3/s ±3.6% based on the variability amongst the 13 gaugings.

The student's-t test method was used to test for bias (degree to which gaugings fall "more on one side of the rating table than on the other"), and the Chi-squared test for degree of scatter around the mean difference observed. The results of the bias and precision tests are shown in Table A.1. Also shown is a plot of the expected versus the observed distribution of differences in Figure A.1

The orange shaded data fields indicate the results for each test. These show a "FAIL" result for bias (at the 5% significance level) but a PASS result for degree of scatter about the mean difference.

These together result in an overall "REJECT DATA- systematic bias is too large" result. This suggests the need to investigate and find the cause of the bias, and if necessary, shift the rating to match the new gaugings, and to obtain more gaugings over a larger stage range, to better enable this shift.

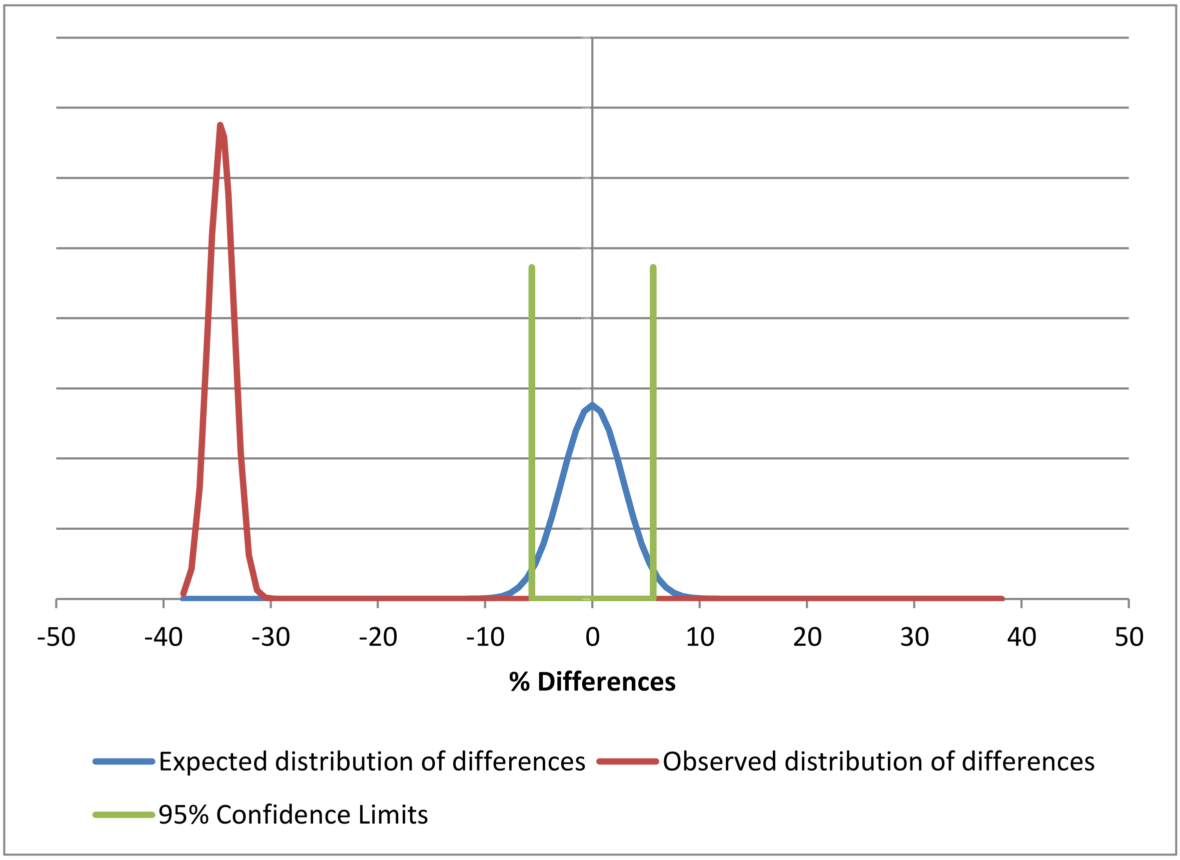


Figure 20: Kalewa - observed versus expected distribution of differences

Note that the observed distribution of difference is well outside the 95%ile confidence limits on the expected distribution of differences.

		Data entered by:-	Glenn McDermott		
STATION:-	DHM009 Chindwin @ Kalewa				
Rating Table number:-	1				
Significance level	5%				
Rating Table Uncertainty	4.0%	(from Section A.5.1)			
Check method Uncertainty	4.0%	(from section A.5.2)			
Confidence Level	95%				

Observation No	**Gauging no &/or date**	*Flowrate Measurements in cumecs*		Differences in measurements	
		Rating Table	***ADCP***	***Cumecs***	*Logarithms*
1	10:30_20/02/2017	689.7	448.8	-240.9	-0.186616087
2	10:36_20/02/2017	689.7	442.4	-247.3	-0.19286965
3	10:42_20/02/2017	689.7	449.9	-239.8	-0.185556782
4	10:48_20/02/2017	689.7	448.7	-241.0	-0.186694478
5	10:58_20/02/2017	689.7	454.3	-235.4	-0.181362422
6	11:05_20/02/2017	689.7	442.1	-247.6	-0.193136764
7	11:13_20/02/2017	689.7	452.1	-237.6	-0.183421877
8	11:50_20/02/2017	689.7	440.4	-249.3	-0.194860253
9	11:54_20/02/2017	689.7	464.4	-225.3	-0.171724999
10	12:00_20/02/2017	689.6	444.2	-245.4	-0.190989369
11	12:06_20/02/2017	689.6	451.6	-238.0	-0.183864477
12	12:13_20/02/2017	689.7	457.9	-231.8	-0.177932265
13	12:21_20/02/2017	689.7	466.1	-223.6	-0.170182987
14					
15					
16					
17					
18					
19					
20					

Number of Observations=	13	
Mean Difference (MD):-	-238.70138	-0.184555
Standard Deviation (STD):-	8.117751	0.007785

BIAS TEST (for Systematic Bias)

(as per AS3778 Part 2.3)

t	-106.0207512	-85.48006892	
p	0.0000000	0.0000000	(Two Tail)

Rated discharges FAIL the Bias Test (ie. There is Systematic bias) at the Confidence Level of:- 95%

PRECISION TEST (for degree of Random Scatter)

	ADCP			Rating Table	
	uncertainty	4.0%		uncertainty	4.0%
expected STD (Log)	0.009045455			0.009045455	expected STD (Log)
			Expected Variance (Log)	0.000163641	

Observed Chi squared	4.443802	
Theoretical Chi squared	21.026070	(One Tail)

Rated discharges PASS the Precision Test (ie. Acceptable Random scatter), at the confidence level of:- 95%

Reject Data - Systematic bias is too large

Table 8: Chindwin at Kalewa difference statistics test results

Sensitivity of rating to channel hydraulics

Although the hydraulic cause of the observed significant differences between the gaugings and the rating is unknown, the magnitude of the suspected slope and/or roughness change can be calculated using Mannings equation.

The ratio of the square root of slope to the roughness coefficient is called the conveyance factor “K”, such that:

$$Q = KAR^{2/3}$$

At this site the average stage during the gaugings was 2.244m, which defines the following channel parameters: Area= 1468.3 sq.m, P= 305.4m, and so; R= 4.81m

The rating table gives a discharge of 689.7 cumecs at this staged height, which defines a conveyance factor “K”= 0.165. The average of the ALS-Hydrgraphics gaugings at this stage is 451.0 cumecs, which defines a reduced “K” factor value of 0.108. This magnitude of “K” reduction could be caused by:

- 53% increase in roughness coefficient (e.g. from build-up of debris on the bed), or;
- 57% reduction in water surface slope (e.g. from build-up of debris at some downstream control feature), or;
- A combination of the two

6.2 Ayeyarwady River at Katha

Characterising ADCP gauging uncertainty

All gaugings were assessed to be of a good quality. The uncertainty due to the scatter of ADCP measurements about their mean value was calculated as twice the standard deviation of the set of values, which gave a figure of ±2.3%. The other more objective uncertainty calculation approach presented in section A.3.1 was also used to calculate an indicative discharge measurement uncertainty for the set of ADCP gaugings, as listed below:

```
ALS Hydrographics NATIONAL

Site     DMH024          Ayeyarwady @ Katha - Sagaing Rgn
VarFrom    100.00        Stream Water Level
VarTo      140.00        Stream Discharge Cumecs
Period   01/10/1999 - 30/09/2018
```

Date	Number	Stage	Flow	Deviation	Area	Velocity	Meth	Temp
10:45_22/02/2017	1.0	1.655	937.100000	7.92	3153.0560	0.297	AD	22.4
11:00_22/02/2017	2.0	1.655	930.568000	7.17	3093.0130	0.301	AD	22.8
11:12_22/02/2017	3.0	1.655	938.758000	8.11	3072.9500	0.305	AD	22.4
11:23_22/02/2017	4.0	1.655	928.583000	6.94	3142.1050	0.296	AD	22.9
11:34_22/02/2017	5.0	1.655	955.738000	10.07	3108.6380	0.307	AD	22.5

Table 9: February 2017 gauging results from Katha with the % deviation from the existing curve

Calculating "u(m)" standard uncertainty due to no. of verticals (ISO 748 Table E.6):-		
Average number of verticals used for set of gauging	**25**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no. of verticals= +/-	**1.76**	%
Assuming a value for "u(s)" for instrument bias factors= +/-	**1**	%
Calculating "u(b)" standard uncertainty of width measurement method (ISO Table E.1):-		
What is the average width of the channel for the set of gaugings?	**390.5**	m
What is the uncertainty of width measurement in terms of +/- metres=	**0.5**	m
Indicative standard uncertainty of width measurement= +/-	**0.128041**	%
Calculating "u(d)" standard uncertainty of depth measurement method (ISO Table E.2):-		
What is the average depth of the channel for the set of gaugings?	**8.0**	m
What is the uncertainty of depth measurement in terms of +/- metres=	**0.01**	m
Indicative standard uncertainty of depth measurement= +/-	**0.125401**	%
Calculating "u(p)" standard uncertainty due to points per vertical (ISO Table E.4):-		
Average number of points per vertical for set of gaugings=	**20**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no points per vertical= +/-	**0.56**	%
Calculating "u(c)" standard uncertainty due to velocity sensor calibration limitations (ISO Table E.5):-		
Average velocity (approximately) for set of gaugings=	**0.301**	m/s
Indicative standard uncertainty due to velocity sensor calibration= +/-	**1.10**	%
Calculating "u(e)" standard uncertainty due to limited exposure time (ISO Table E.3):-		
Average exposure time per point in each vertical, for the set of gaugings?	**0.5**	minutes
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited exposure time= +/-	**6.23**	%
Calculating indicative discharge uncertainty:-		
Standard Uncertainty= +/-	**2.048**	%
Expanded uncertainty at 95%ile=+/-	**4.0**	**%**

Table 10: Ayeyarwady at Katha uncertainty

As this ±4.0% result is larger than the ±2.3% calculated earlier (from the variability of the gauged flows to their mean), then ±4.0% will be adopted here as the characteristic discharge measurement uncertainty of the ADCP gaugings.

Characterising DMH Rating table uncertainty

The figure of ±4.0% was adopted as a realistic match to DMH's own ADCP gaugings - noting that the best fit line (rating) through the gaugings should actually be better than this.

Precision and Bias test results

Five (5) ADCP gaugings were taken over a 1 hour period, during a steady flow regime, with stage (or gauge height) remaining steady at 1.655m throughout the period. This identified an average discharge of 938.1 m^3/s ±2.3% based on the variability amongst the 5 gaugings.

The student's-t test method was used to test for bias (degree to which gaugings fall "more on one side of the rating table than on the other"), and the Chi-squared test for degree of scatter around the mean difference observed. The results of the bias and precision tests are shown in Table A.2. Also shown is a plot of the expected versus the observed distribution of differences in Figure A.2

The orange shaded data fields indicate the results for each test. These show a "FAIL" result for bias (at the 5% significance level) but a PASS result for degree of scatter about the mean difference.

These together result in an overall "REJECT DATA- systematic bias is too large" result. This suggests the need to investigate and find the cause of the bias, and if necessary, to shift the rating to match the new gaugings, and to obtain more gaugings over a larger stage range, to better enable this shift.

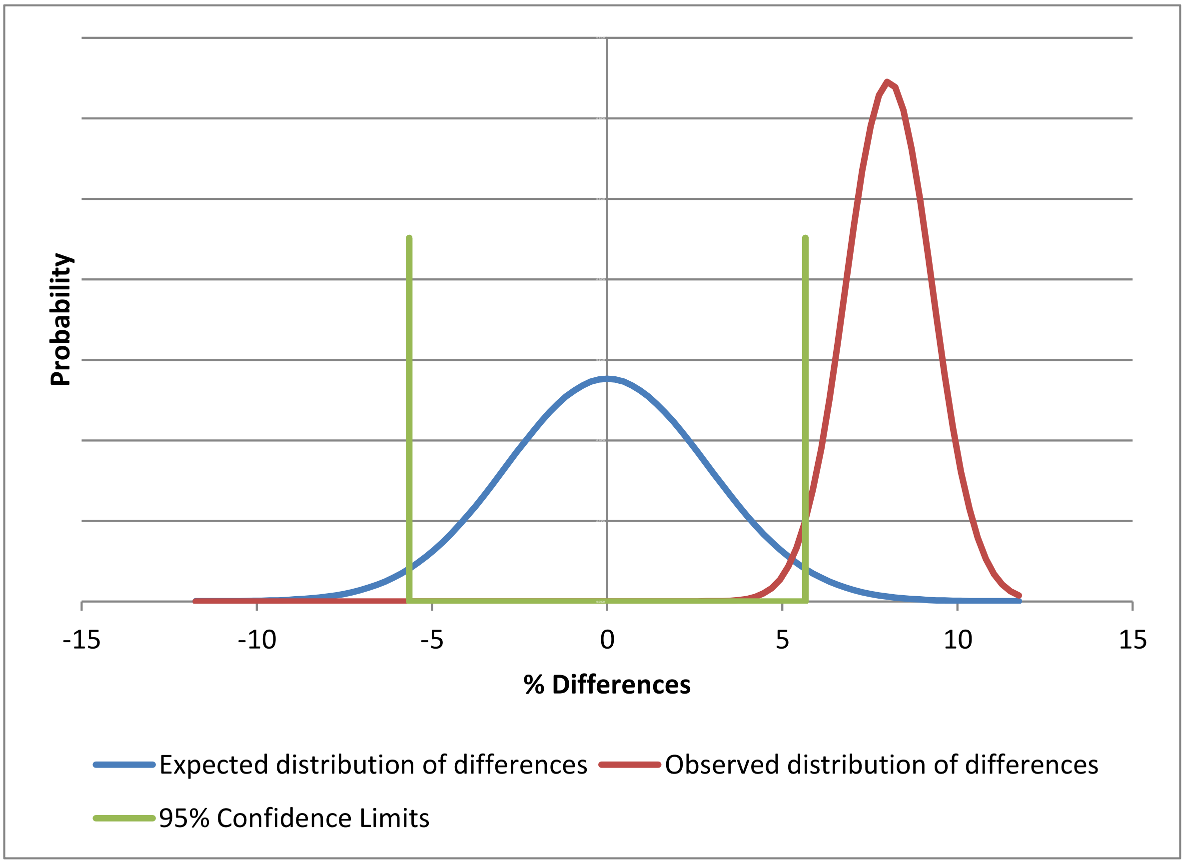


Figure 21: Katha-observed versus expected distribution of differences

Note that the difference distribution plot in Figure A.2.1 above, although showing a small portion of the observed difference distribution as inside the 95%ile confidence limits of the expected distribution, the major portion remains outside.

			Data entered by:-	Glenn McDermott	
STATION:-	DHM024- Ayeyarwady at Katha				
Rating Table number:-	1				
Significance level	5%				
Rating Table Uncertainty	4.0%	(from Section A.5.1)			
ADCP Uncertainty	4.0%	(from section A.5.2)			
Confidence Level	95%				

Observation No	**Gauging no &/or date**	*Flowrate Measurements in cumecs*		Differences in measurements	
		Rating Table	***ADCP***	***Cumecs***	*Logarithms*
1	10:45_22/02/2017	868.3	937.1	68.8	0.033101937
2	11:00_22/02/2017	868.3	930.6	62.3	0.030073231
3	11:12_22/02/2017	868.3	938.8	70.4	0.033865867
4	11:23_22/02/2017	868.3	928.6	60.3	0.02914018
5	11:34_22/02/2017	868.3	955.7	87.4	0.041668966
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Number of Observations=	5	
Mean Difference (MD):-	69.83017	0.033570
Standard Deviation (STD):-	10.728466	0.004943

BIAS TEST (for Systematic Bias)- based on students t-test

(as per ISO 1100 - 1982 version)		t	14.55427123	15.18473204
	Two tail:-	p	0.000129611	0.000109665

Rated discharges FAIL the Bias Test (ie. There is Systematic bias) at the Confidence Level of:- 95%

PRECISION TEST (for degree of Random Scatter)- based on Chi-squared test

	ADCP			Rating Table	
	uncertainty	4.0%		uncertainty	4.0%
expected STD (Log)	0.009045455			0.009045455	expected STD (Log)
			Expected Variance (Log)	0.000163641	

Observed Chi squared	0.597349	
Theoretical Chi squared	9.487729	(One Tail)

Rated discharges PASS the Precision Test (ie. Acceptable Random scatter), at the confidence level of:- 95%

Reject Data - Systematic bias is too large

Table 11: Ayeyarwady at Katha difference statistics test results

Sensitivity of rating to channel hydraulics

Although the hydraulic cause of the observed significant differences between the gaugings and the rating is unknown, the magnitude of the suspected slope and/or roughness change can be calculated using Mannings equation.

The ratio of the square root of slope to the roughness coefficient is called the conveyance factor "K", such that:

$$Q = KAR^{2/3}$$

At this site the average stage during the gaugings was 1.655m, which defines the following channel parameters: Area= 3114.0 sq.m, P= 393.8m, and so; R= 7.91m

The rating table gives a discharge of 868.3 cumecs at this staged height, which defines a conveyance factor "K"= 0.070. The average of the ALS-Hydrgraphics gaugings at this stage is 938.1 cumecs, which defines an increased "K" factor value of 0.076. This magnitude of "K" increase could be caused by:

- 7.5% decrease in roughness coefficient (e.g. from erosion of debris on the bed), or;
- 17% increase in water surface slope (e.g. from clearing away or removal of debris at some downstream control feature), or;
- A combination of the two

6.3 Ayeyarwady River at Sagaing

Characterising ADCP gauging uncertainty

All gaugings were assessed to be of a good quality. The uncertainty due to the scatter of ADCP measurements about their mean value was calculated as twice the standard deviation of the set of values, which gave a figure of ±6.2%. The other more objective uncertainty calculation approach presented in section A.3.1 was also used to calculate an indicative discharge measurement uncertainty for the set of ADCP gaugings, as listed below:

```
ALS Hydrographics NATIONAL

Site     DMH028          Ayeyarwady @ Sagaing - Mandalay Region
VarFrom    100.00        Stream Water Level
VarTo      140.00        Stream Discharge Cumecs
Period  01/10/1999 - 30/09/2018
```

Date	Number	Stage	Flow	Deviation	Area	Velocity	Meth	Temp
11:36_24/02/2017	1.0	2.192	1271.893000	82.98	4472.9380	0.284	AD	25.3
11:53_24/02/2017	2.0	2.192	1196.623000	72.15	4412.1430	0.271	AD	25.8
12:50_24/02/2017	3.0	2.192	1246.521000	79.33	4339.7530	0.287	AD	25.1

Table 12: February 2017 gauging results from Sagaing with the % deviation from the existing curve

Calculating "u(m)" standard uncertainty due to no. of verticals (ISO 748 Table E.6):-		
Average number of verticals used for set of gauging	**25**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no. of verticals= +/-	**1.76**	%
Assuming a value for "u(s)" for instrument bias factors= +/-	**1**	%
Calculating "u(b)" standard uncertainty of width measurement method (ISO Table E.1):-		
What is the average width of the channel for the set of gaugings?	**1006.8**	m
What is the uncertainty of width measurement in terms of +/- metres=	**0.5**	m
Indicative standard uncertainty of width measurement= +/-	**0.049662**	%
Calculating "u(d)" standard uncertainty of depth measurement method (ISO Table E.2):-		
What is the average depth of the channel for the set of gaugings?	**4.4**	m
What is the uncertainty of depth measurement in terms of +/- metres=	**0.01**	m
Indicative standard uncertainty of depth measurement= +/-	**0.228387**	%
Calculating "u(p)" standard uncertainty due to points per vertical (ISO Table E.4):-		
Average number of points per vertical for set of gaugings=	**20**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no points per vertical= +/-	**0.56**	%
Calculating "u(c)" standard uncertainty due to velocity sensor calibration limitations (ISO Table E.5):-		
Average velocity (approximately) for set of gaugings=	**0.281**	m/s
Indicative standard uncertainty due to velocity sensor calibration= +/-	**1.16**	%
Calculating "u(e)" standard uncertainty due to limited exposure time (ISO Table E.3):-		
Average exposure time per point in each vertical, for the set of gaugings?	**0.5**	minutes
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited exposure time= +/-	**6.53**	%
Calculating indicative discharge uncertainty:-		
Standard Uncertainty= +/-	**2.050**	%
Expanded uncertainty at 95%ile=+/-	**4.0**	**%**

Table 13: Ayeyarwady River at Sagaing uncertainty

As this ±4.0% result is LESS than the ±6.2% calculated earlier (from the variability of the gauged flows to their mean), then ±6.2% will be adopted here as the characteristic discharge measurement uncertainty of the ADCP gaugings.

Characterising DMH Rating table uncertainty

The figure of ±4.0% was adopted as a realistic match to DMH's own ADCP gaugings- noting that the best fit line (rating) through the gaugings should actually be better than this.

Precision and Bias test results

Three (3) ADCP gaugings were taken over a 1 hour and 15 minutes period, during a steady flow regime, with stage (or gauge height) remaining steady at 2.192m throughout the period. This identified an average discharge of 1238.3 m^3/s ±6.2% based on the variability amongst the 3 gaugings.

Note that "3" is the absolute minimum number of gaugings that the statistical testing software can be run on, without giving unrealistic results. However, as only three were available in this 1km wide river section, they were used in the tests.

The student's-t test method was used to test for bias (degree to which gaugings fall "more on one side of the rating table than on the other"), and the Chi-squared test for degree of scatter around the mean difference observed. The results of the bias and precision tests are shown in Table A.3a. Also shown is a plot of the expected versus the observed distribution of differences in Figure A.3a

The orange shaded data fields indicate the results for each test. These show a "FAIL" result for bias (at the 5% significance level) but a PASS result for degree of scatter about the mean difference.

These together result in an overall "REJECT DATA- systematic bias is too large" result. This suggests the need to investigate and find the cause of the bias, and if necessary, to shift the rating to match the new gaugings, and to obtain more gaugings over a larger stage range, to better enable this shift.

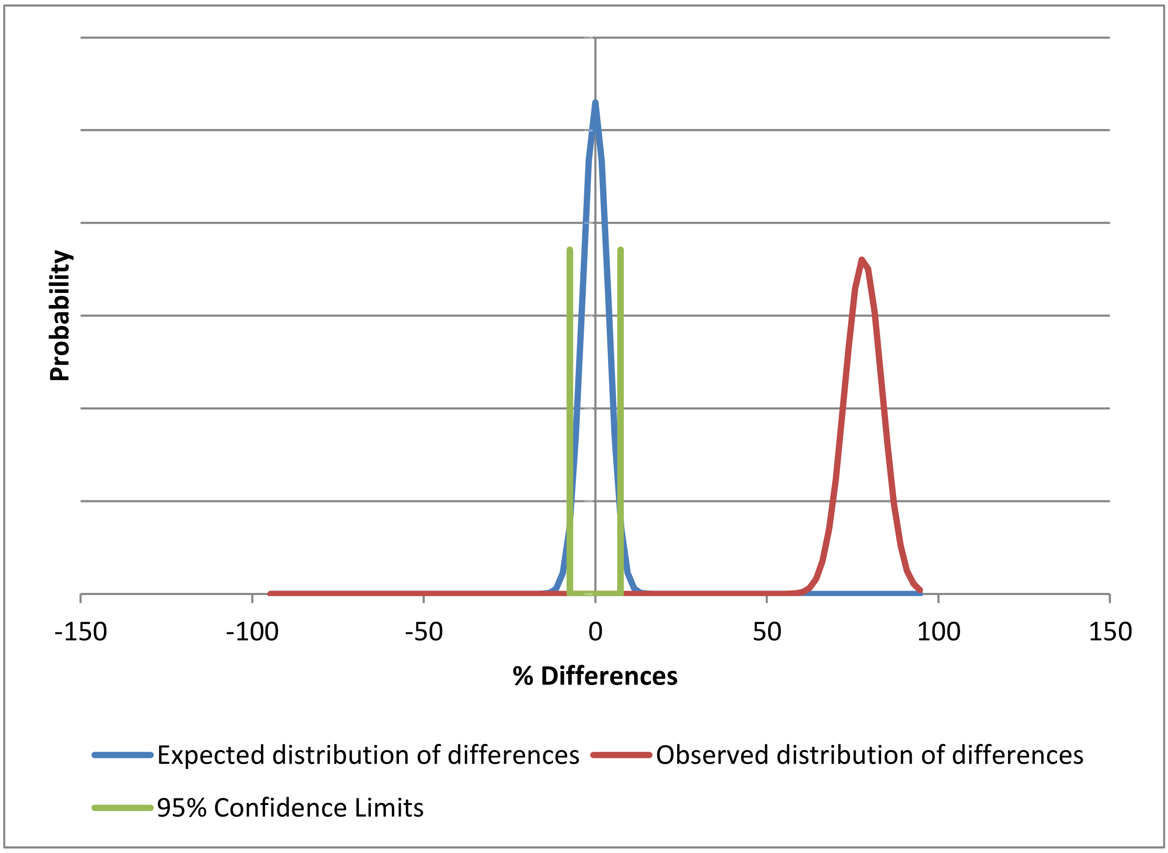


Figure 22: Sagaing - observed versus expected distribution of differences

Note that the difference distribution plot in Figure 22 above, shows clearly that the observed differences distribution is well outside the 95%ile confidence limits of the expected differences distribution.

		Data entered by:-	Glenn McDermott		
STATION:-	DHM028- Ayeyarwady at Sagaing				
Rating Table number:-	1				
Significance level	5%				
Rating Table Uncertainty	4.0%	(from Section A.6.1)			
ADCP Uncertainty	6.2%	(from section A.6.2)			
Confidence Level	95%				

Observation No	Gauging no &/or date	Flowrate Measurements in cumecs		Differences in measurements	
		Rating Table	ADCP	Cumecs	Logarithms
1	11:36_24/02/2017	695.1	1271.893	576.8	0.262403623
2	11:53_24/02/2017	695.1	1196.623	501.5	0.235907027
3	12:50_24/02/2017	695.1	1246.521	551.4	0.253652948
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Number of Observations=	3	
Mean Difference (MD):-	543.24457	0.250655
Standard Deviation (STD):-	38.298159	0.013500

BIAS TEST (for Systematic Bias)- based on students t-test

(as per ISO 1100 - 1982 version)		t	24.56847068	32.1580851
	Two tail:-	p	0.001652594	0.000965584

Rated discharges FAIL the Bias Test (ie. There is Systematic bias) at the Confidence Level of:- 95%

PRECISION TEST (for degree of Random Scatter)- based on Chi-squared test

	ADCP			Rating Table	
	uncertainty	4.0%		uncertainty	6.2%
expected STD (Log)	0.009045455			0.014182486	expected STD (Log)
			Expected Variance (Log)	0.000282963	

Observed Chi squared	1.288226	
Theoretical Chi squared	5.991465	(One Tail)

Rated discharges PASS the Precision Test (ie. Acceptable Random scatter), at the confidence level of:- 95%

Reject Data - Systematic bias is too large

Table 14: Ayeyarwady at Sagaing difference statistics test results

Note: The changes are of large magnitude, suggesting the possibility that the DMH rating table supplied may not be the right one for this site- as evidenced by the close resultant match obtained (i.e. no change in rating required) using the DMH rating photographed on the wall of the site building.

Note: The writing on figure 23 is that of the author's done subsequently to extrapolate the alternative rating

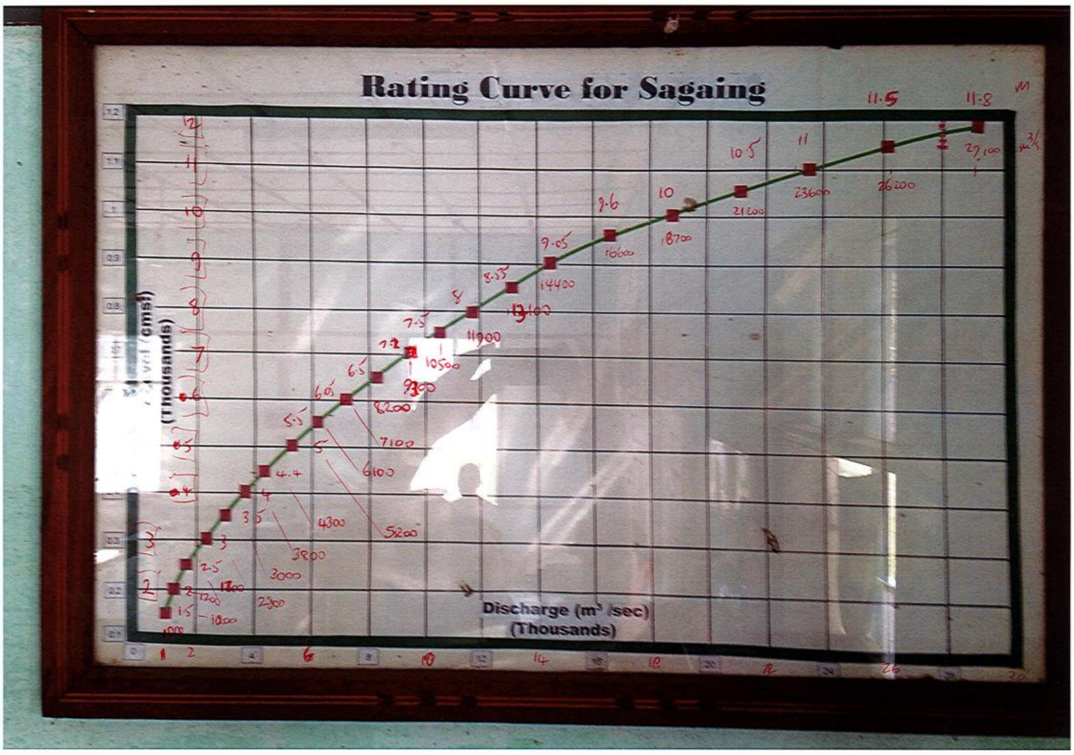


Figure 23: This photo shows the extrapolated rating used in the review for Sagaing

IF the DHM rating was derived from a hydrodynamic model of the river, then the rating will be a result of the surveyed river cross sections used as input to the model, as well as the roughness factors assumed for bed and banks. If the cross sections were surveyed some time ago, they may need to be re-done, or re-surveyed at closer intervals.

The ALS-Hydrgraphics gaugings show a significant difference between the DHM rating table for that stage height and the observed ALS-Hydrgraphics gauged discharge. Although we have provided a postulated rating table change, in the long run it would be better to base the revision either on more gaugings over a larger stage range, OR on revising the inputs to the model and rerunning it, such that its roughness settings are adjusted to replicate the ALS-Hydrgraphics gaugings and stage height. The revised rating can then be extracted from the model results file, and would show a match with the ALS-Hydrgraphics gaugings.

Test results if the on-site rating curve is used

The ALS-Hydrgraphics field team pointed out that the on-site rating curve, as shown in the photograph in the main body of the report, was substantially different to the rating curve provided, but showed a much better match to the ADCP gauged flowrates. This photographed rating curve was used to extract the rated discharge for a gauge height of 2.19m, and gave a figure of approximately 1300 cumecs.

When this revised rated discharge is used, the revised test results that pass are shown in Table 15 and Figure 24.

	Data entered by:-	**Glenn McDermott**
STATION:-	DHM028- Ayeyarwady at Sagaing	
Rating Table number:-	1	
Significance level	5%	
Rating Table Uncertainty	4.0%	(from Section A.6.1)
ADCP Uncertainty	6.2%	(from section A.6.2)
Confidence Level	95%	

Observation No	**Gauging no &/or date**	*Flowrate Measurements in cumecs*		Differences in measurements	
		Rating Table	***ADCP***	***Cumecs***	*Logarithms*
1	11:36_24/02/2017	1300.0	1271.893	-28.1	-0.009492775
2	11:53_24/02/2017	1300.0	1196.623	-103.4	-0.035986006
3	12:50_24/02/2017	1300.0	1246.521	-53.5	-0.018243753
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Number of Observations=	3	
Mean Difference (MD):-	-61.65433	-0.021241
Standard Deviation (STD):-	38.295173	0.013499

BIAS TEST (for Systematic Bias)- based on students t-test

(as per ISO 1100 - 1982 version)		t	-2.788561305	-2.725502687
	Two tail:-	p	0.108137398	0.112377253

Rated discharges PASS the Bias Test (ie. No Systematic bias) at the Confidence Level of:- 95%

PRECISION TEST (for degree of Random Scatter)- based on Chi-squared test

	ADCP			Rating Table	
	uncertainty	4.0%		uncertainty	6.2%
expected STD (Log)	0.009045455			0.014182486	expected STD (Log)
			Expected Variance (Log)	0.000282963	

Observed Chi squared	1.287869	
Theoretical Chi squared	5.991465	(One Tail)

Rated discharges PASS the Precision Test (ie. Acceptable Random scatter), at the confidence level of:- 95%

Accept Data

Table 15: Ayeyarwady at Sagaing difference statistics test results- revised using 1300 m^3/s

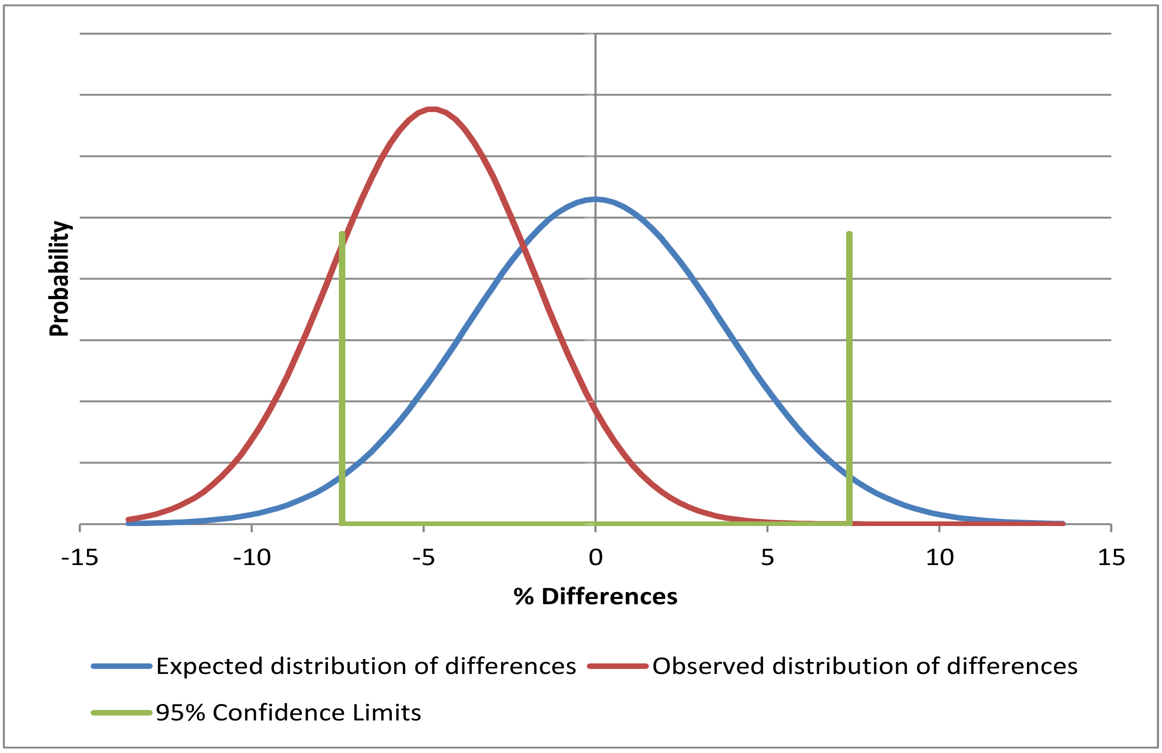


Figure 24: Sagaing - observed versus expected distribution of differences-revised using 1300 m^3/s

Using the revised rated discharge of 1300 cumecs gives a much better fit with the ADCP gaugings, such that the observed difference mostly fall within the 95%ile confidence limits of the expected distribution of differences- resulting in an “Accept Data” result.

Sensitivity of rating to channel hydraulics

IF the revised rated discharge of 1300 cumecs is used, then the bias and precision test results suggest there is no need to explain the differences, as they are within the measurement uncertainties of the ADCP and rating discharge methods.

HOWEVER if the DMH rating as-supplied is used, the likely range of causes and their magnitudes are set out below:

> Although the hydraulic cause of the observed significant differences between the gaugings and the rating is unknown, the magnitude of the suspected slope and/or roughness change can be calculated using Mannings equation
>
> The ratio of the square root of slope to the roughness coefficient is called the conveyance factor “K”, such that:
>
> $$Q = KAR^{2/3}$$
>
> At this site the average stage during the gaugings was 2.19m, which defines the following channel parameters: Area= 4408.3 sq.m, P= 1011.4m, and so; R= 4.36m
>
> The rating table gives a discharge of 695.1 cumecs at this staged height, which defines a conveyance factor “K”= 0.059. The average of the ALS-Hydrgraphics gaugings at this stage is 1238.3 cumecs, which defines an increased “K” factor value of 0.105. This magnitude of “K” increase could be caused by:

- 42% decrease in roughness coefficient (e.g. from erosion of debris on the bed), or;
- 217% increase in water surface slope (e.g. from clearing away or removal of debris at some downstream control feature), or;
- A combination of the two

IF a re-survey and revised model is constructed and calibrated, then it can also be used to check on the existence and magnitude of loop-rating (hysteresis) effects at each site, by running it in unsteady flow mode and inputting a large storm and inflows to the model. The model calculated depths and discharges could then be extracted from each particular model node, and plotted against each other- which will reveal the existence and magnitude of any loop-rating effects.

6.4 Ayeyarwady River at Nyaung Oo

Unlike the other sites which each had a single flowing channel, this site has two distinct and separate channels. It has been assumed that the on-site level sensor represents the water level in both channels, and that no second level sensor is required.

Characterising ADCP gauging uncertainty

All gaugings were assessed to be of a good quality. The uncertainty due to the scatter of ADCP measurements about their mean value was calculated as twice the standard deviation of the set of values, which gave a figure of ±0.4% (noting that there were only 2 gaugings to base this variability calculation upon- which are not enough). The other more objective uncertainty calculation approach was also used to calculate an indicative discharge measurement uncertainty for the set of ADCP gaugings, as listed below:

```
ALS Hydrographics NATIONAL

Site     DMH039          Ayeyarwady @ Nyaung Oo - Mandalay Region
VarFrom   100.00         Stream Water Level
VarTo     140.00         Stream Discharge Cumecs
Period  01/10/1999 - 30/09/2018

Date                  Number      Stage          Flow Deviation       Area Velocity Meth  Temp
12:14_25/02/2017         1.0     10.903    2018.793000     -21.86  5722.5450     0.000 AD    26.0
12:21_25/02/2017         2.0     10.903    2025.001000     -21.62  5567.6030     0.000 AD    26.0
```

Table 16: February 2017 gauging results from Nyaung Oo with the % deviation from the existing curve

Figure 25: Gauging at Nyaung Oo

Calculating "u(m)" standard uncertainty due to no. of verticals (ISO 748 Table E.6):-		
Average number of verticals used for set of gauging	**25**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no. of verticals= +/-	**1.76**	%
Assuming a value for "u(s)" for instrument bias factors= +/-	**1**	%
Calculating "u(b)" standard uncertainty of width measurement method (ISO Table E.1):-		
What is the average width of the channel for the set of gaugings?	**2040.3**	m
What is the uncertainty of width measurement in terms of +/- metres=	**0.5**	m
Indicative standard uncertainty of width measurement= +/-	**0.024506**	%
Calculating "u(d)" standard uncertainty of depth measurement method (ISO Table E.2):-		
What is the average depth of the channel for the set of gaugings?	**2.8**	m
What is the uncertainty of depth measurement in terms of +/- metres=	**0.01**	m
Indicative standard uncertainty of depth measurement= +/-	**0.361428**	%
Calculating "u(p)" standard uncertainty due to points per vertical (ISO Table E.4):-		
Average number of points per vertical for set of gaugings=	**20**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no points per vertical= +/-	**0.56**	%
Calculating "u(c)" standard uncertainty due to velocity sensor calibration limitations (ISO Table E.5):-		
Average velocity (approximately) for set of gaugings=	**0.358**	m/s
Indicative standard uncertainty due to velocity sensor calibration= +/-	**0.97**	%
Calculating "u(e)" standard uncertainty due to limited exposure time (ISO Table E.3):-		
Average exposure time per point in each vertical, for the set of gaugings?	**0.5**	minutes
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited exposure time= +/-	**5.53**	%
Calculating indicative discharge uncertainty:-		
Standard Uncertainty= +/-	**2.045**	%
Expanded uncertainty at 95%ile=+/-	**4.0**	**%**

Table 17: Ayeyarwady River at Nyaung Oo uncertainty

As this ±4.0% result is MORE than the ±0.4% calculated earlier (from the variability of the gauged flows to their mean), then ±4.0% will be adopted here as the characteristic discharge measurement uncertainty of the ADCP gaugings.

Characterising DMH Rating table uncertainty

A figure of ±4.0% was adopted as a realistic match to DMH's own ADCP gaugings- noting that the best fit line (rating) through the gaugings should actually be better than this.

Precision and Bias test results

Two (2) ADCP gaugings were taken over a 15 minute period, during a steady flow regime, with stage (or gauge height) remaining steady at 10.903m throughout the period. This identified an average discharge of 2021.9 m^3/s ±0.4% based on the variability amongst the 2 gaugings.

Note that 2 gaugings are really too few to base the precision and bias tests upon. However they have still been input to the test sheet here, as the tests indicate what "common sense" suggests- a "reject data" result, due to systematic bias.

The student's-t test method was used to test for bias (degree to which gaugings fall "more on one side of the rating table than on the other"), and the Chi-squared test for degree of scatter around the mean difference observed. The results of the bias and precision tests are shown in Table A.4. Also shown is a plot of the expected versus the observed distribution of differences in Figure A.4

The orange shaded data fields indicate the results for each test. These show a "FAIL" result for bias (at the 5% significance level) but a PASS result for degree of scatter about the mean difference.

These together result in an overall "REJECT DATA- systematic bias is too large" result. This suggests the need to investigate and find the cause of the bias, and if necessary, to shift the rating to match the new gaugings, and to obtain more gaugings over a larger stage range, to better enable this shift.

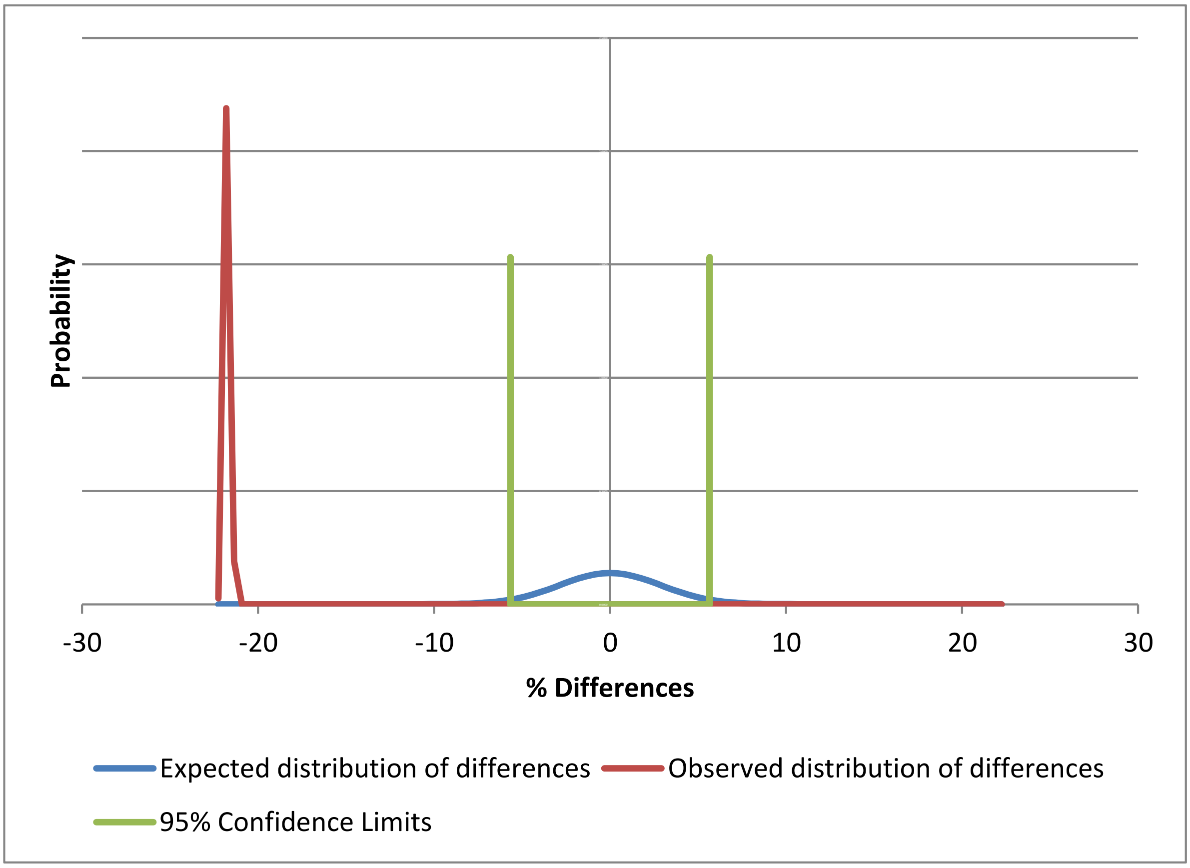


Figure 26: Nyaung 0o - observed versus expected distribution of differences

Note that the difference distribution plot in Figure 26 above, shows clearly that the observed differences distribution is well outside the 95%ile confidence limits of the expected differences distribution.

			Data entered by:-	Glenn McDermott	
STATION:-	DHM039 Ayeyarwady at Nyaung 0o				
Rating Table number:-	1				
Significance level	5%				
Rating Table Uncertainty	4.0%	(from Section A.7.1)			
ADCP Uncertainty	4.0%	(from section A.7.2)			
Confidence Level	95%				

Observation No	**Gauging no &/or date**	*Flowrate Measurements in cumecs*		Differences in measurements	
		Rating Table	***ADCP***	***Cumecs***	*Logarithms*
1	12:14_25/02/2017	2583.6	2018.793	-564.8	-0.107126593
2	12:21_25/02/2017	2583.6	2025.001	-558.6	-0.105794741
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Number of Observations=	2	
Mean Difference (MD):-	-561.66675	-0.106461
Standard Deviation (STD):-	4.382990	0.000942

BIAS TEST (for Systematic Bias)- based on students t-test

(as per ISO 1100 - 1982 version)		t	-181.2271283	-159.8685841
	Two tail:-	p	0.003512793	0.003982092

Rated discharges FAIL the Bias Test (ie. There is Systematic bias) at the Confidence Level of:- 95%

PRECISION TEST (for degree of Random Scatter)- based on Chi-squared test

	ADCP			Rating Table	
	uncertainty	4.0%		uncertainty	4.0%
expected STD (Log)	0.009045455			0.009045455	expected STD (Log)
			Expected Variance (Log)	0.000163641	

Observed Chi squared	0.005420	
Theoretical Chi squared	3.841459	(One Tail)

Rated discharges PASS the Precision Test (ie. Acceptable Random scatter), at the confidence level of:- 95%

Reject Data - Systematic bias is too large

Table 18: Ayeyarwady at Nyaung 0o - difference statistics test results

Sensitivity of rating to channel hydraulics

Although the hydraulic cause of the observed significant differences between the gaugings and the rating is unknown, the magnitude of the suspected slope and/or roughness change can be calculated using Mannings equation.

The ratio of the square root of slope to the roughness coefficient is called the conveyance factor “K”, such that:

$$Q = KAR^{2/3}$$

At this site the average stage during the gaugings was 10.903m, which defines the following channel parameters: Area= 5645.1 sq.m, P= 2045.5m, and so; R= 2.76m

The rating table gives a discharge of 2583.6 cumecs at this staged height, which defines a conveyance factor “K”= 0.233. The average of the ALS-Hydrgraphics gaugings at this stage is 2021.9 cumecs, which defines a decreased “K” factor value of 0.182. This magnitude of “K” decrease could be caused by:

- 28% increase in roughness coefficient (e.g. from build-up of debris on the bed), or;
- 39% decrease in water surface slope (e.g. from build-up of debris at some downstream control feature), or;
- A combination of the two

6.5 Ayeyarwady River at Zalun

Characterising ADCP gauging uncertainty

All gaugings were assessed to be of a good quality. The uncertainty due to the scatter of ADCP measurements about their mean value was calculated as twice the standard deviation of the set of values, which gave a figure of ±3.0%. The other more objective uncertainty calculation approach presented in section A.3.1 was also used to calculate an indicative discharge measurement uncertainty for the set of ADCP gaugings, as listed below:

```
ALS Hydrographics NATIONAL

Site     DMH047            Ayeyarwady @ Zalun - Ayeyarwady
VarFrom    100.00          Stream Water Level
VarTo      140.00          Stream Discharge Cumecs
Period   01/10/1999 - 30/09/2018
```

Date	Number	Stage	Flow	Deviation	Area	Velocity	Meth
13:00_17/02/2017	1.0	2.239	2381.696000	-22.49	5917.3990	0.402	AD
13:05_17/02/2017	2.0	2.249	2298.608000	-25.65	5932.6010	0.387	AD
13:14_17/02/2017	3.0	2.274	2353.545000	-25.02	5916.4830	0.398	AD
13:35_17/02/2017	4.0	2.335	2329.555000	-27.82	5877.3040	0.396	AD

Table 19: February 2017 gauging results from Zalun with the % deviation from the existing curve

Calculating "u(m)" standard uncertainty due to no. of verticals (ISO 748 Table E.6):-		
Average number of verticals used for set of gauging	**25**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no. of verticals= +/-	**1.76**	%
Assuming a value for "u(s)" for instrument bias factors= +/-	**1**	%
Calculating "u(b)" standard uncertainty of width measurement method (ISO Table E.1):-		
What is the average width of the channel for the set of gaugings?	**623.9**	m
What is the uncertainty of width measurement in terms of +/- metres=	**0.5**	m
Indicative standard uncertainty of width measurement= +/-	**0.080141**	%
Calculating "u(d)" standard uncertainty of depth measurement method (ISO Table E.2):-		
What is the average depth of the channel for the set of gaugings?	**9.5**	m
What is the uncertainty of depth measurement in terms of +/- metres=	**0.01**	m
Indicative standard uncertainty of depth measurement= +/-	**0.105551**	%
Calculating "u(p)" standard uncertainty due to points per vertical (ISO Table E.4):-		
Average number of points per vertical for set of gaugings=	**20**	
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited no points per vertical= +/-	**0.56**	%
Calculating "u(c)" standard uncertainty due to velocity sensor calibration limitations (ISO Table E.5):-		
Average velocity (approximately) for set of gaugings=	**0.396**	m/s
Indicative standard uncertainty due to velocity sensor calibration= +/-	**0.91**	%
Calculating "u(e)" standard uncertainty due to limited exposure time (ISO Table E.3):-		
Average exposure time per point in each vertical, for the set of gaugings?	**0.5**	minutes
(ie conservative equivalent to ADCP)		
Indicative standard uncertainty due to limited exposure time= +/-	**5.16**	%
Calculating indicative discharge uncertainty:-		
Standard Uncertainty= +/-	**2.042**	%
Expanded uncertainty at 95%ile=+/-	**4.0**	**%**

Table 20: Ayeyarwady River at Zalun uncertainty

As this ±4.0% result is MORE than the ±3.0% calculated earlier (from the variability of the gauged flows to their mean), then ±4.0% will be adopted here as the characteristic discharge measurement uncertainty of the ADCP gaugings.

A.5.2 Characterising DMH Rating table uncertainty

As explained in section A.3.2, a figure of ±4.0% would normally have been adopted as typical. HOWEVER the field team noted that this site was affected by downstream tide effects. In fact the gauge height rose 0.1m during the 35 minutes it took them to take 4 gaugings with the ADCP. The fact that tide effects are present means that a single rating table for the site will be more uncertain than ±4%. How much more uncertain depends on how far upstream the site is relative to the river outlet.

In the low flow and stage range a family of rating curves can be expected, which all join back to a single rating curve at some higher stage. In the absence of any detailed analyses of the nature and magnitude of tide effects at this site, and any DMH ADCP gaugings that may have been taken it is impossible to accurately define an indicative uncertainty for the provided DMH rating table. Until such analysis is done, a figure of ±10% will be adopted as more realistic than ±4%.

A.5.3 Precision and Bias test results

Four (4) ADCP gaugings were taken over a 35 minute period, during a flow regime with gradually increasing levels- presumably affected by the downstream tide rising to high tide level. However for the sake of this text the mean stage height was 2.274m ±0.05m. The average ADCP discharge was 2340.9 m^3/s ±3.0% based on the variability amongst the 2 gaugings.

Note that the ±3.0% variability in gauged flowrate is typical of the variabilities noted during steady flow conditions at the other sites. This suggests that flows were steady during the ADCP gaugings at Zalun, despite the effect of the incoming saltwater wedge beneath the freshwater river flow, which did have the effect of causing stage levels to rise.

The student's-t test method was used to test for bias (degree to which gaugings fall "more on one side of the rating table than on the other"), and the Chi-squared test for degree of scatter around the mean difference observed. The results of the bias and precision tests are shown in Table A.5. Also shown is a plot of the expected versus the observed distribution of differences in Figure A.5

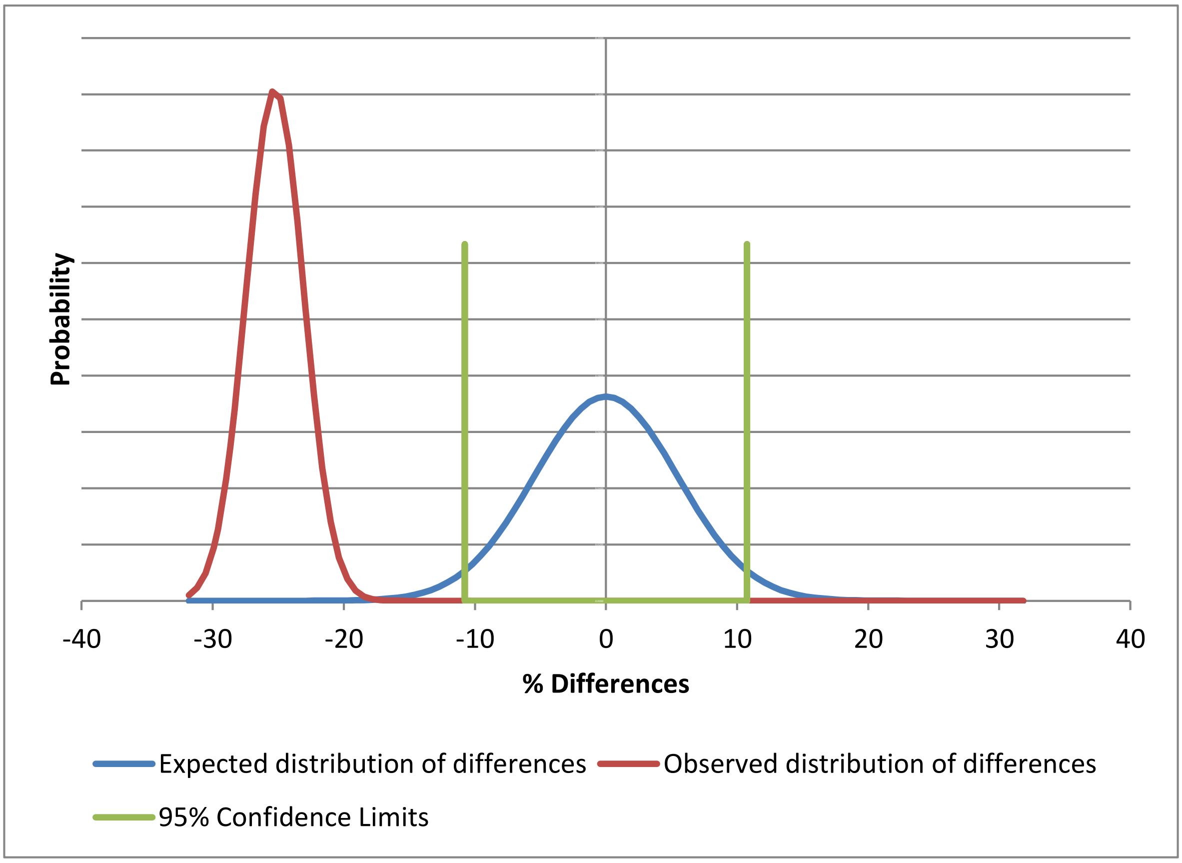


Figure 27: Zalun - observed versus expected distribution of differences

Note that the difference distribution plot in Figure 27 above, shows clearly that the observed differences distribution is still well outside the 95%ile confidence limits of the expected differences distribution, even with the wider "expected" difference distribution resultant from assuming ±10% instead of ±4% as the characteristic uncertainty of the DMH rating table.

		Data entered by:-	**Glenn McDermott**		
STATION:-	DHM047 Ayeyarwady at Zalun				
Rating Table number:-	1				
Significance level	5%				
Rating Table Uncertainty	10.0%	(from Section A.8.1)			
ADCP Uncertainty	4.0%	(from section A.8.2)			
Confidence Level	95%				

Observation No	**Gauging no &/or date**	*Flowrate Measurements in cumecs*		Differences in measurements	
		Rating Table	***ADCP***	***Cumecs***	*Logarithms*
1	13:00_17/02/2017	3072.8	2381.696	-691.1	-0.110642263
2	13:05_17/02/2017	3091.6	2298.608	-793.0	-0.128719027
3	13:14_17/02/2017	3138.9	2353.545	-785.4	-0.125054564
4	13:35_17/02/2017	3227.4	2329.555	-897.9	-0.141583122
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Number of Observations=	4	
Mean Difference (MD):-	-791.82044	-0.126500
Standard Deviation (STD):-	84.541030	0.012728

BIAS TEST (for Systematic Bias)- based on students t-test

(as per ISO 1100 - 1982 version)		t	-18.73221643	-19.87789003
	Two tail:-	p	0.000332097	0.000278238

Rated discharges FAIL the Bias Test (ie. There is Systematic bias) at the Confidence Level of:- 95%

PRECISION TEST (for degree of Random Scatter)- based on Chi-squared test

	ADCP			Rating Table		
	uncertainty	10.0%		uncertainty	4.0%	
expected STD (Log)	0.023346087			0.009045455	expected STD (Log)	
			Expected Variance (Log)		0.00062686	

Observed Chi squared	0.775264	
Theoretical Chi squared	7.814728	(One Tail)

Rated discharges PASS the Precision Test (ie. Acceptable Random scatter), at the confidence level of:- 95%

Reject Data - Systematic bias is too large

Table 21: Ayeyarwady at Zalun- difference statistics test results

The orange shaded data fields indicate the results for each test. These show a “FAIL” result for bias (at the 5% significance level) but a PASS result for degree of scatter about the mean difference.

These together result in an overall “REJECT DATA- systematic bias is too large” result. This suggests the need to investigate and find the cause of the bias, and if necessary, to shift the rating to match the new gaugings, and to obtain more gaugings over a larger stage range, to better enable this shift.

One factor which can already be identified is the effect of the tide on the discharge rating at this site, which may alone explain the significant differences observed.

Sensitivity of rating to channel hydraulics

Although the hydraulic cause of the observed significant differences between the gaugings and the rating is unknown, the magnitude of the suspected slope and/or roughness change can be calculated using Mannings equation.

The ratio of the square root of slope to the roughness coefficient is called the conveyance factor “K”, such that:

$$Q = KAR^{2/3}$$

At this site the average stage during the gaugings was 2.274m ±0.05m, which defines the following channel parameters: Area= 5910.9 sq.m, P= 637.3m, and so; R= 9.28m

The rating table gives a discharge of 3132.7 cumecs at this mean staged height, which defines a conveyance factor “K”= 0.120. The average of the ALS-Hydrgraphics gaugings at this stage is 2340.9 cumecs, which defines a decreased “K” factor value of 0.090. This magnitude of “K” decrease could be caused by:

- 34% increase in roughness coefficient (e.g. from build-up of debris on the bed), or;
- 44% decrease in water surface slope (e.g. TIDAL EFFECTS, &/or, from build-up of debris at some downstream control feature), or;
- A combination of the two

Figure 28: Gauging while capacity building at Zalun

6.6 Summary of test results

At the sites with a “Reject Rating” outcome, further investigations and gaugings over a wider range of stage levels should be taken to have a higher level of confidence in any changes to rating tables.

The table below summarises the test results for the 5 sites:

Monitoring site	No. of ADCP gaugings	Significance of differences Test results[2]			Comments
		Bias test	**Precision test**	**Overall**	
DMH009 at Kalewa	13	Fail	Pass	Reject rating	
DMH024 at Katha	5	Fail	Pass	Reject rating	
DMH028 at Sagaing	3	Fail	Pass	Reject rating	
DMH028 at Sagaing- using other rating	3	Pass	Pass	Accept rating	This rating was the one photographed on site
DMH037 at Nyaung 0o	2	Fail	Pass	Reject rating	Two channels
DMH047 at Zalun	4	Fail	Pass	Reject rating	Tidal affected- see advice in 8.4 & 8.5

Table 22: Test results summary

Figure 29: Left bank of the Sagaing gauging site

[2] Using a characteristic rating table discharge uncertainty of ±4% for all sites except DMH047, which was made to have ±10% due to tidal influence, and; using an ADCP gauging uncertainty of ±4%, except for site DMH028 which had a ±6.2% uncertainty due to internal variability of the gaugings taken

7 Rating review results

7.1 Chindwin River at Kalewa

Figure 30: Cross-section and gaugings were recorded at the site where the DMH take their measurements

ALS Hydrographics NATIONAL

Chindwin @ Kalewa - Sagaing Rgn

Rating Table 1.01 DMH009

Stage (m)	Area (sqm)	H.Rad.(m)
-5.000	0.000	0.000
-4.000	16.339	0.323
-3.000	80.811	1.03
-2.000	167.654	1.78
-1.000	269.027	2.47
0.000	385.256	3.05
1.000	523.129	3.47
2.000	710.544	3.41
3.000	936.619	3.81
4.000	1199.728	4.25
5.000	1499.516	4.69
6.000	1835.981	5.15
7.000	2239.239	4.93
8.000	2730.622	5.30
9.000	3249.457	6.17
10.000	3779.511	7.02
11.000	4320.852	7.84
12.000	4876.918	8.59
13.000	5449.619	9.32
14.000	6038.956	10.0
15.000	6645.050	10.7

ALS Hydrographics NATIONAL

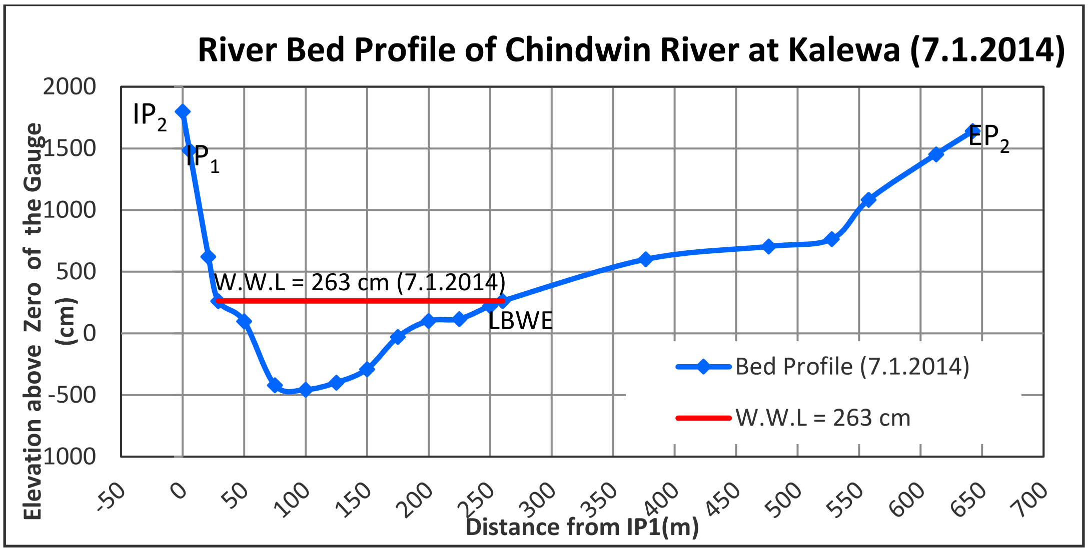
Chindwin @ Kalewa - Sagaing Rgn

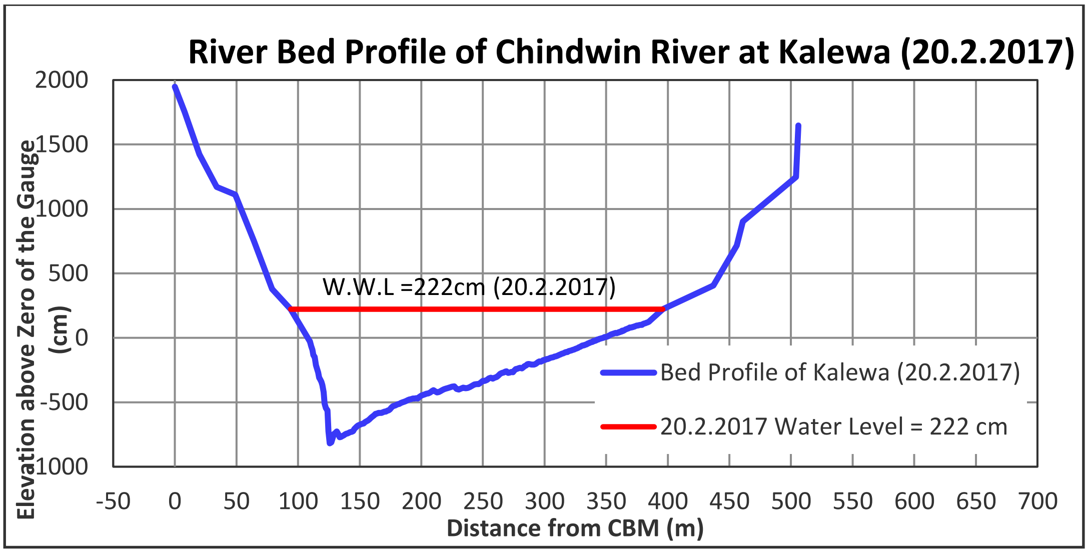
Rating Table 3.01 HyChannl

Stage (m)	Area (sqm)	H.Rad.(m)
-5.000	91.658	1.42
-4.000	170.974	1.71
-3.000	297.434	2.02
-2.000	457.219	2.53
-1.000	650.171	3.07
0.000	873.785	3.60
1.000	1131.151	4.05
2.000	1420.174	4.71
3.000	1731.362	5.24
4.000	2074.018	5.74
5.000	2443.474	6.35
6.000	2836.294	6.95
7.000	3252.474	7.53
8.000	3695.674	7.96
9.000	4172.494	8.38
10.000	4670.436	9.23
11.000	5176.025	10.1
12.000	5696.734	10.6
13.000	6231.063	11.5
14.000	6773.538	12.3
15.000	7323.500	13.1

Tables 23 & 24: Kalewa old area rating on the left; new area rating is on the right

Tables 23 & 24 show the difference in the area tables between January 2014 and February 2017. Figures 29 & 30 below show that although the cross-section details were not recorded at the exact location they were recorded close enough to show that the stream bed has changed considerably in the last three years





Figures 29 & 30: Kalewa - observed change in cross section over time

To be able to compare like with like, it is essential that the cross-section / gauging location be clearly recorded for perpetuity

Based on the gaugings, the new area table, the new hydraulic radii and the derived coefficients of discharge (K), Figure 31 below indicates how the existing coefficients of discharge for the existing rating was interpolated to suit the new hydraulic conditions of the site. This is the basis of the newly derived rating table.

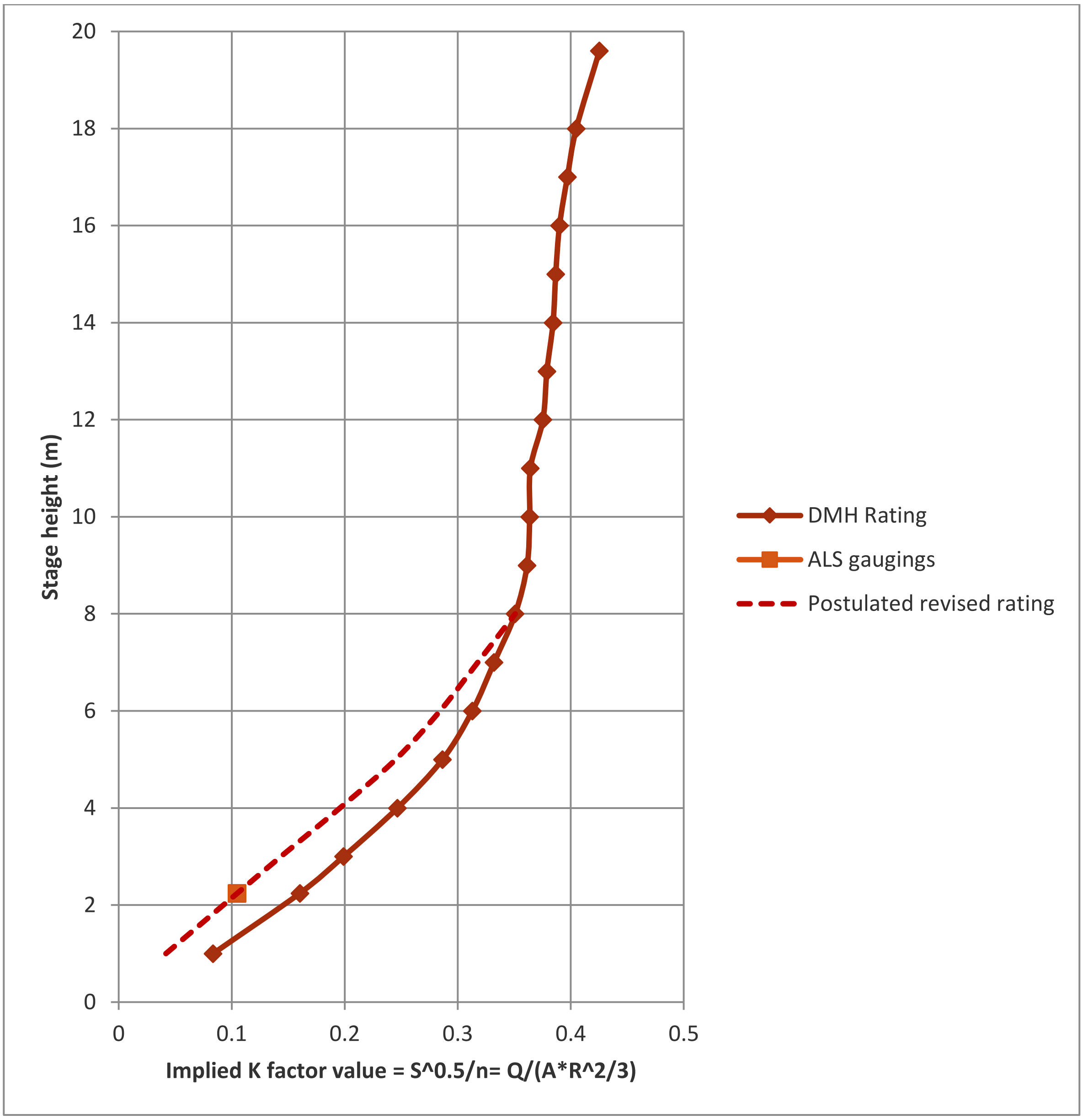


Figure 31: Kalewa - observed and modified K factor values for rating table modification

The rating table was only modified below 8 metres for several reasons:

- The K values start to plateaux at approximately 8 metres
- There was not enough gaugings at higher values to support any changes above 8 metres
- There seemed to be little change to the river profile above 8 metres

The resulting changes to the rating are indicated on the following two figures that show how the gaugings previously all plotted on the left (low) side of the curve whereas now the curve bisects the group of gaugings relatively evenly, giving the gauging an acceptable level of bias.

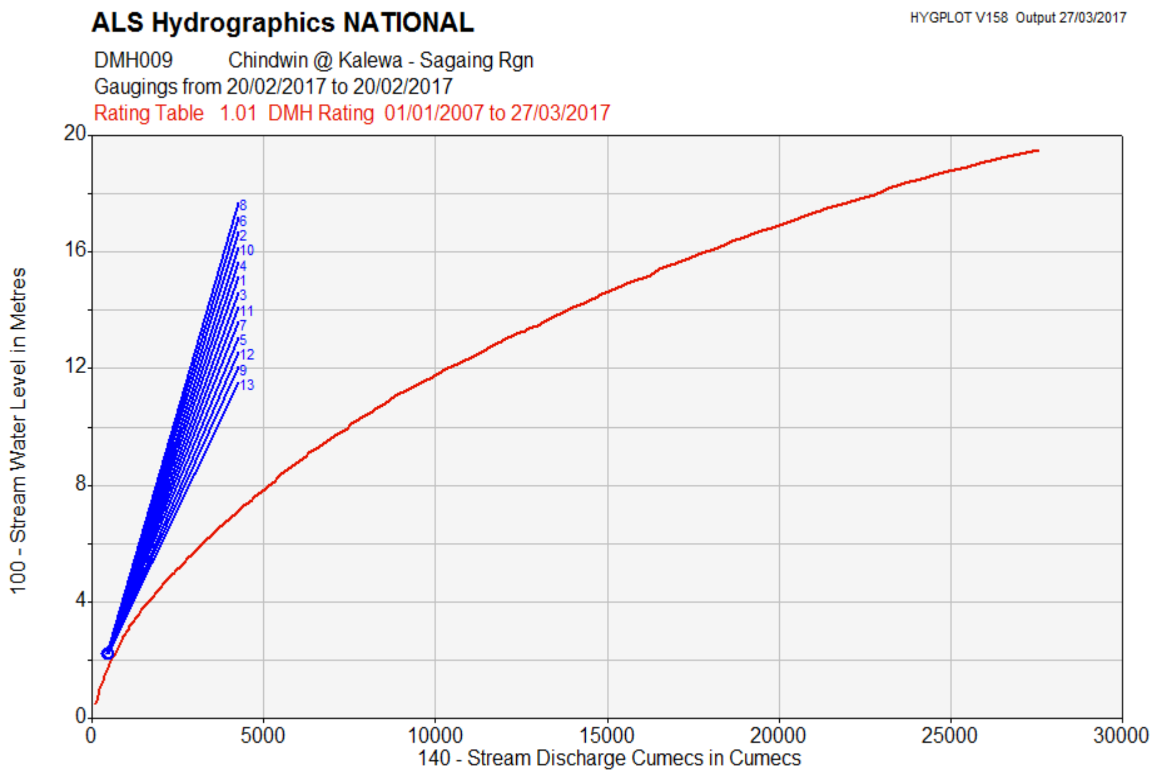


Figure 32: Kalewa – February 2017 gauging results plotted against the original rating curve

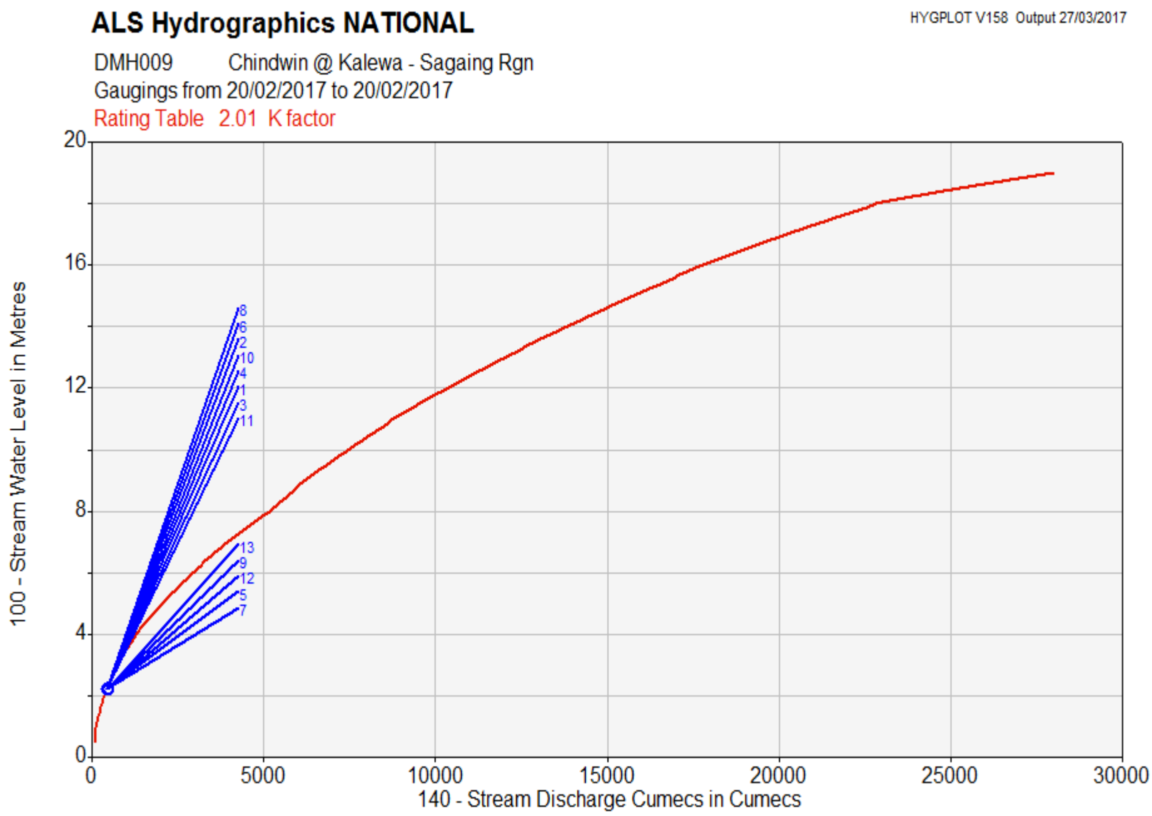


Figure 33: Kalewa – February 2017 gauging results plotted against the modified K factor rating curve

7.2 Ayeyarwady River at Katha

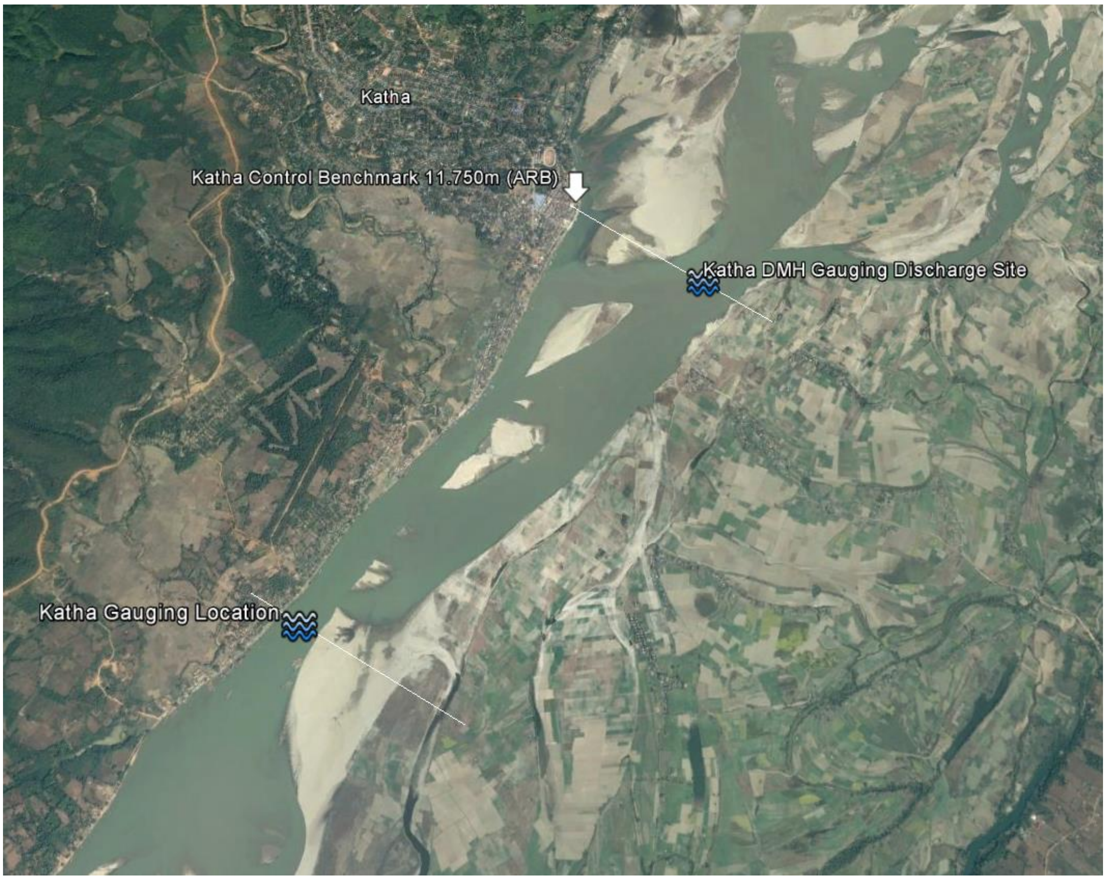


Figure34: Katha cross-section and gaugings were recorded at a different site from where the DMH take their measurements due to stream conditions at the time

ALS Hydrographics NATIONAL
Ayeyarwady @ Katha - Sagaing Rgn
Rating Table 1.01 DMH024

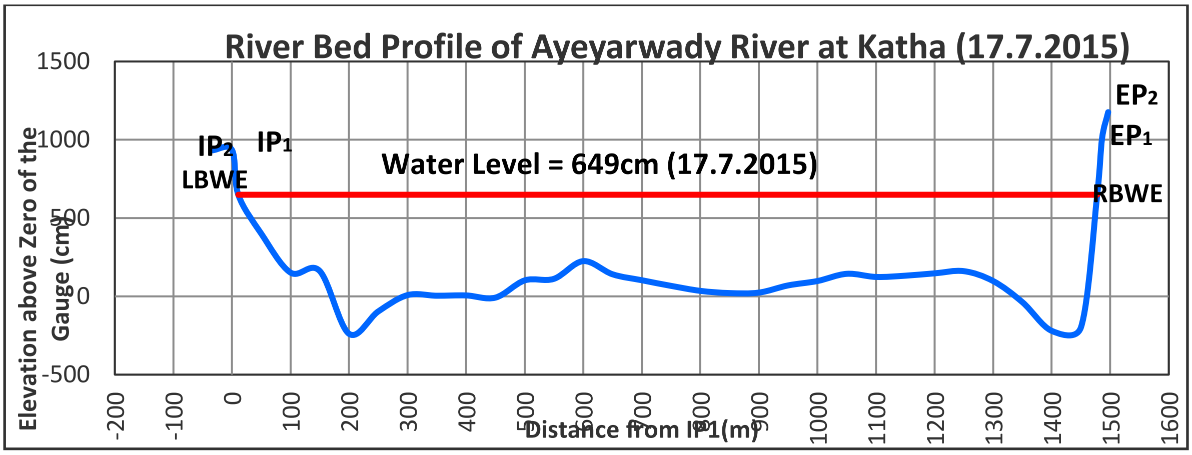
Stage (m)	Area (sqm)	H.Rad.(m)
-3.000	0.000	0.000
-2.000	8.699	0.125
-1.000	121.571	0.799
0.000	320.518	1.15
1.000	908.319	1.13
2.000	2064.080	1.53
3.000	3445.662	2.47
4.000	4853.395	3.42
5.000	6282.373	4.36
6.000	7730.398	5.30
7.000	9195.785	6.25
8.000	10668.827	7.22
9.000	12147.972	8.18

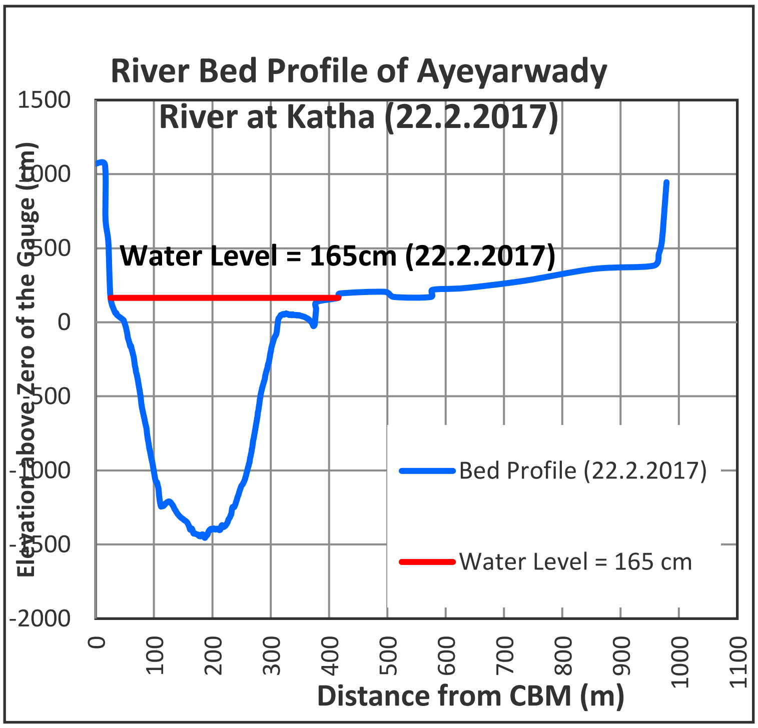
ALS Hydrographics NATIONAL
Ayeyarwady @ Katha - Sagaing Rgn
Rating Table 3.01 HyChannl

Stage (m)	Area (sqm)	H.Rad.(m)
-5.000	1398.157	6.74
-4.000	1608.465	7.38
-3.000	1829.829	7.98
-2.000	2061.815	8.61
-1.000	2305.827	9.05
0.000	2564.698	9.43
1.000	2879.066	8.21
2.000	3270.774	6.35
3.000	3912.005	5.26
4.000	4744.762	5.05
5.000	5685.731	5.98
6.000	6634.661	6.93
7.000	7588.921	7.88
8.000	8547.009	8.85
9.000	9507.372	9.81

Table 25 & 26: Katha old area rating on the left; new area rating is on the right

Tables 25 & 26 show the difference in the area tables between July 2015 and February 2017. Figures 35 & 36 below show that although the cross-section details were not recorded at the exact location they were recorded close enough to show that the stream bed has changed considerably in the last three years.





Figures 35 & 36:
Katha - observed change in cross section over time (and at different locations) shown in the approximately the same scale

To be able to compare like with like, it is essential that the cross-section / gauging location be clearly recorded for perpetuity.

Based on the gaugings, the new area table, the new hydraulic radii and the derived coefficients of discharge (K), Figure 37 below indicates how the existing coefficients of discharge for the existing rating was interpolated to suit the new hydraulic conditions of the site. This is the basis of the newly derived rating table.

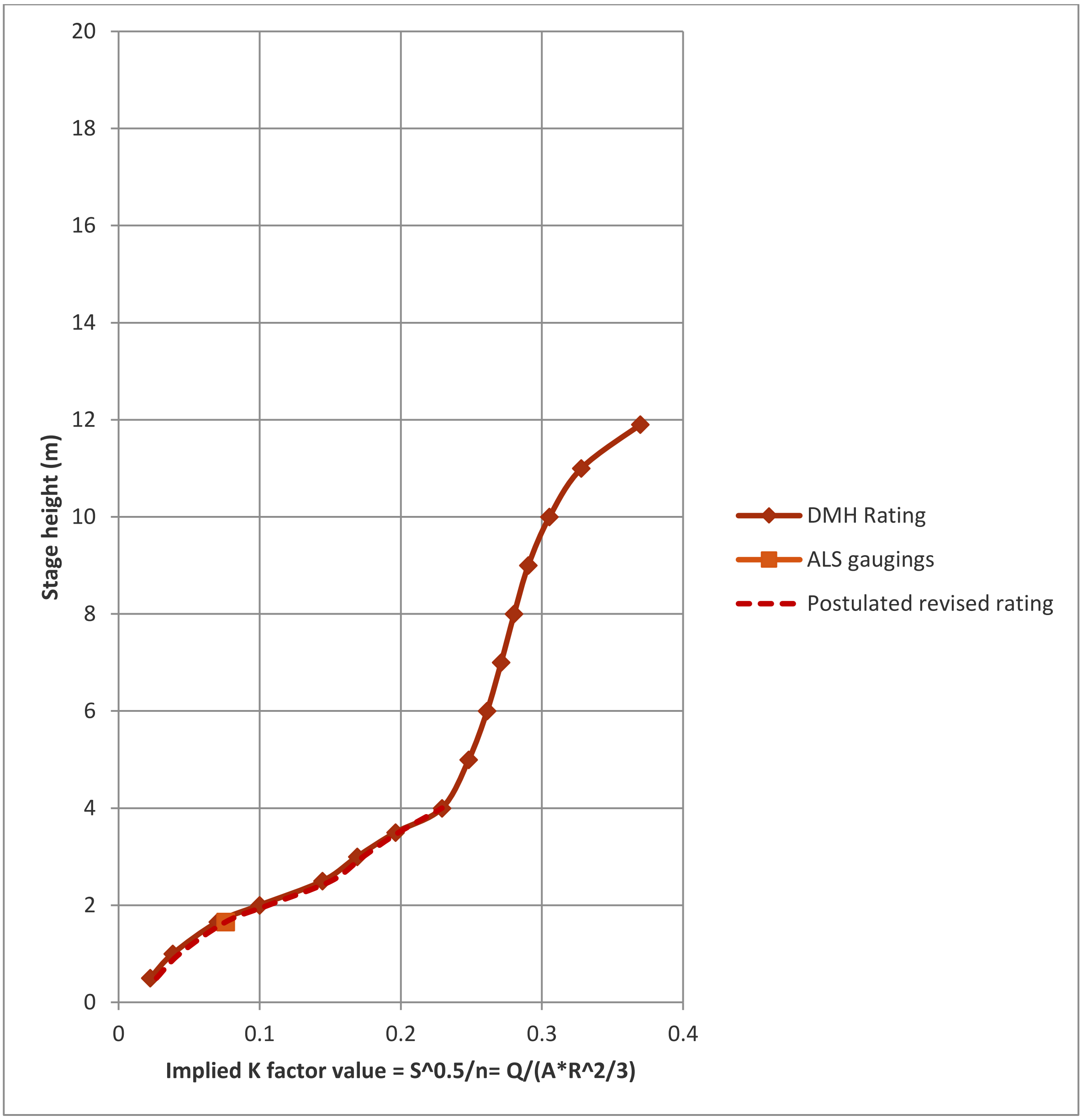


Figure 37: Katha - observed and modified K factor values for rating table modification

The rating table was only modified below 4 metres for several reasons:

- The K values start to plateaux at approximately 4 metres
- There was not enough gaugings at higher values to support any changes above 4 metres
- There seemed to be little change to the river profile above 4 metres

The resulting changes to the rating are indicated on the following two figures that show how the gaugings previously all plotted on the right (high) side of the curve whereas now the curve bisects the group of gaugings evenly, giving the gauging an acceptable level of bias.

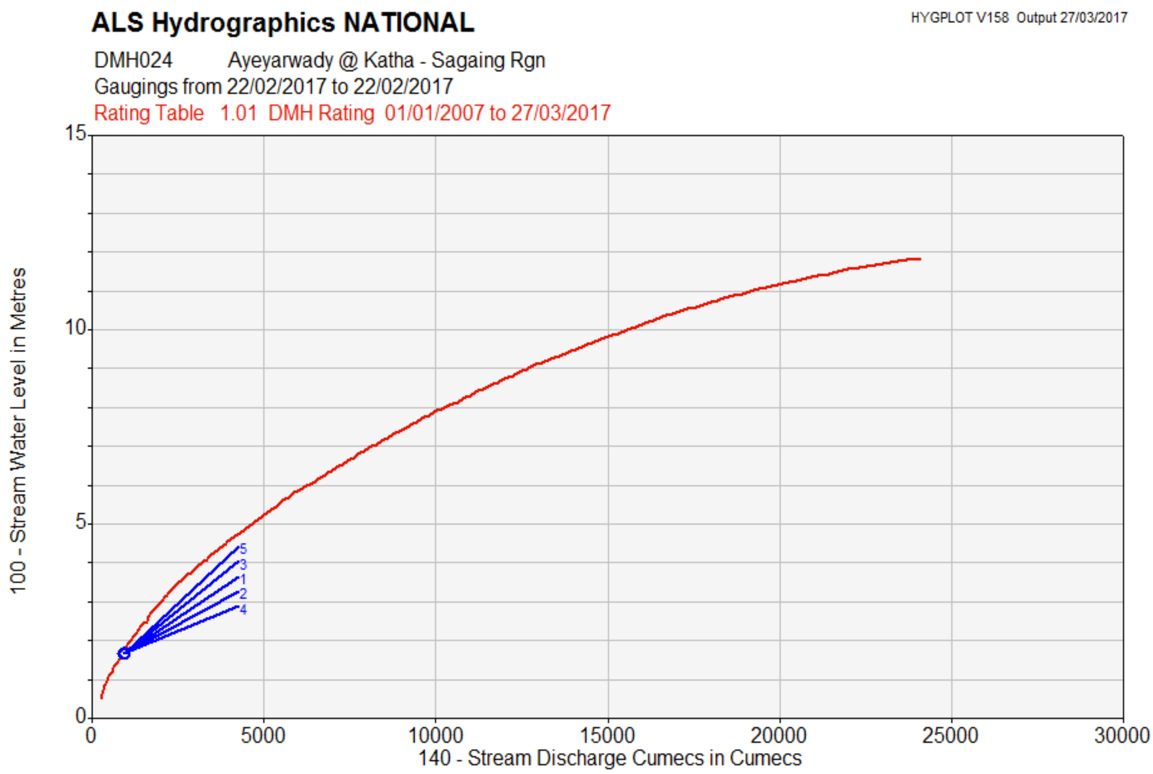


Figure 38: Katha – February 2017 gauging results plotted against the original rating curve

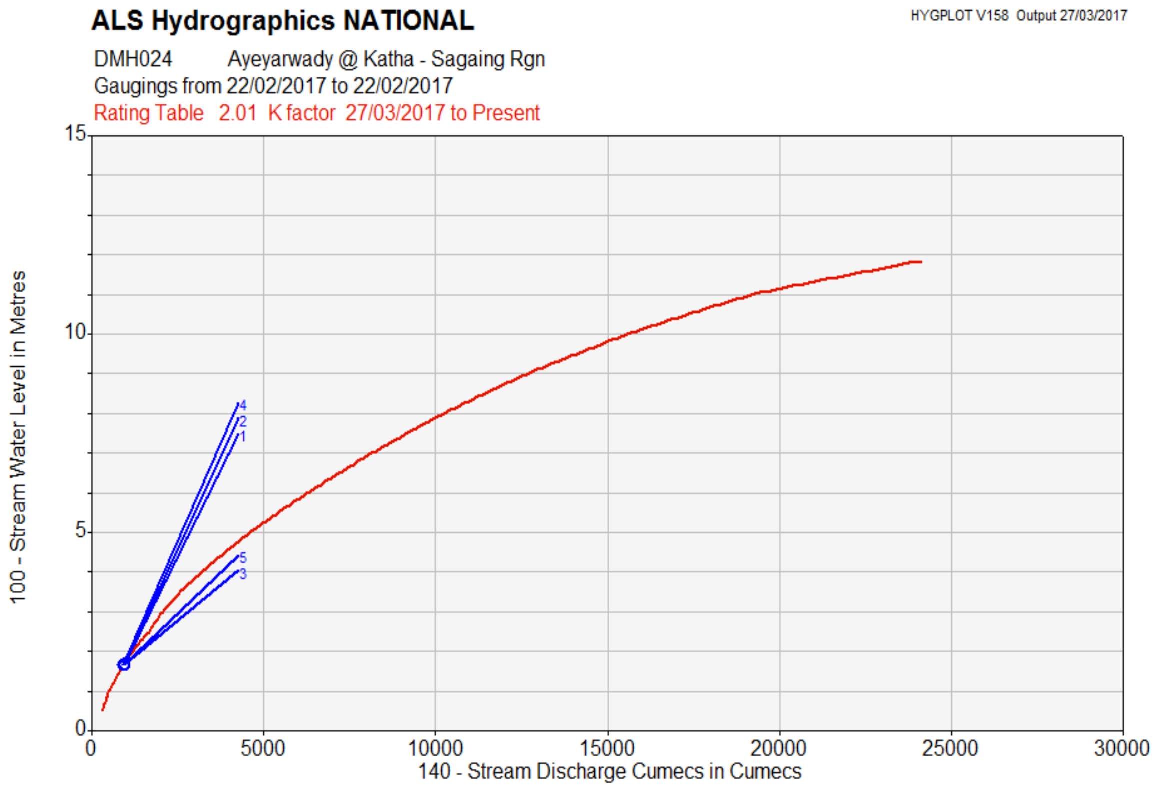
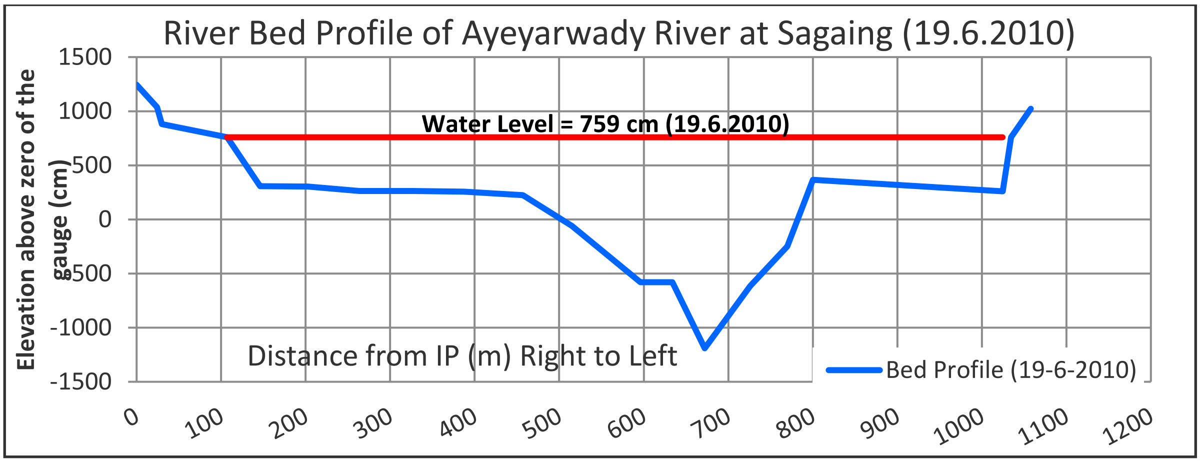
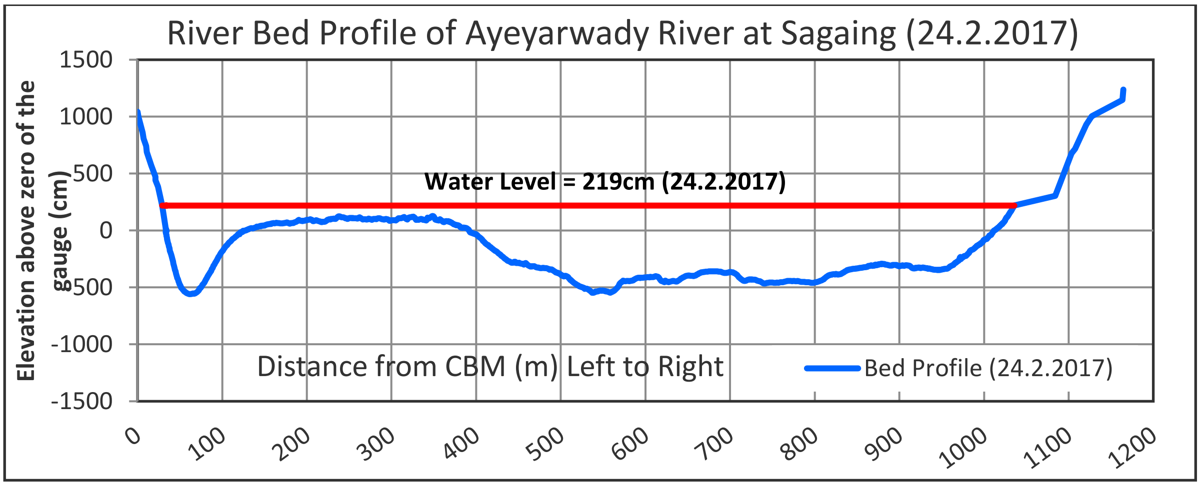


Figure 39: Katha – February 2017 gauging results plotted against the modified K factor rating curve

7.3 Ayeyarwady River at Sagaing

Figure 40: Cross-section and gaugings were recorded at the site where the DMH take their measurements





Figures 41 & 42: Sagaing - observed change in cross section between June 2010 and February 2017

Figure 43 below shows that the rating that was provided by the DMH gives a large discrepancy between it and the gaugings taken 25/02/17 of approximately 80%. This is unacceptable. Figure 44 below shows that the original rating derived from a picture on the wall of the staff office at Sagaing gives is a small discrepancy between it and the gaugings taken 25/02/17 of approximately 4%. This is acceptable and therefore it is recommended that the original rating derived from the photograph be accepted as the appropriate rating for the Sagaing site for now.

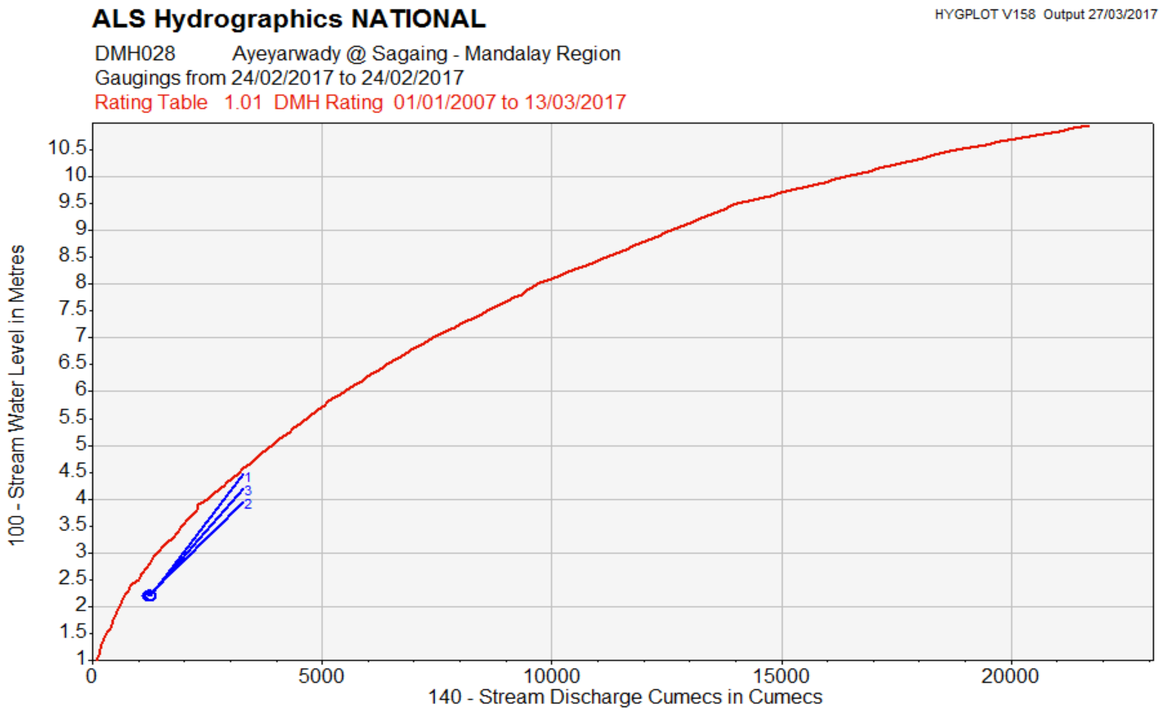


Figure 43: Sagaing – February 2017 gauging results plotted against the original rating curve

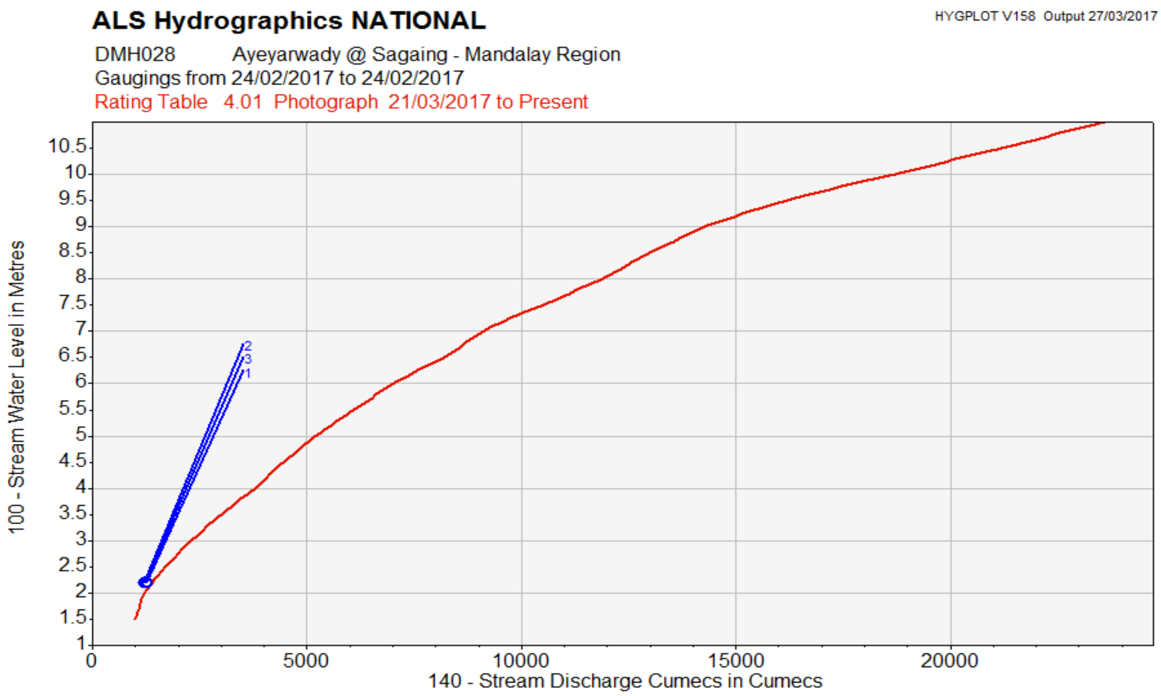


Figure 44: Sagaing – February 2017 gauging results plotted against the rating curve discovered on site

7.4 Ayeyarwady River at Nyaung Oo

Figure 45: Nyaung Oo - observed change in cross section over time (and at different locations)

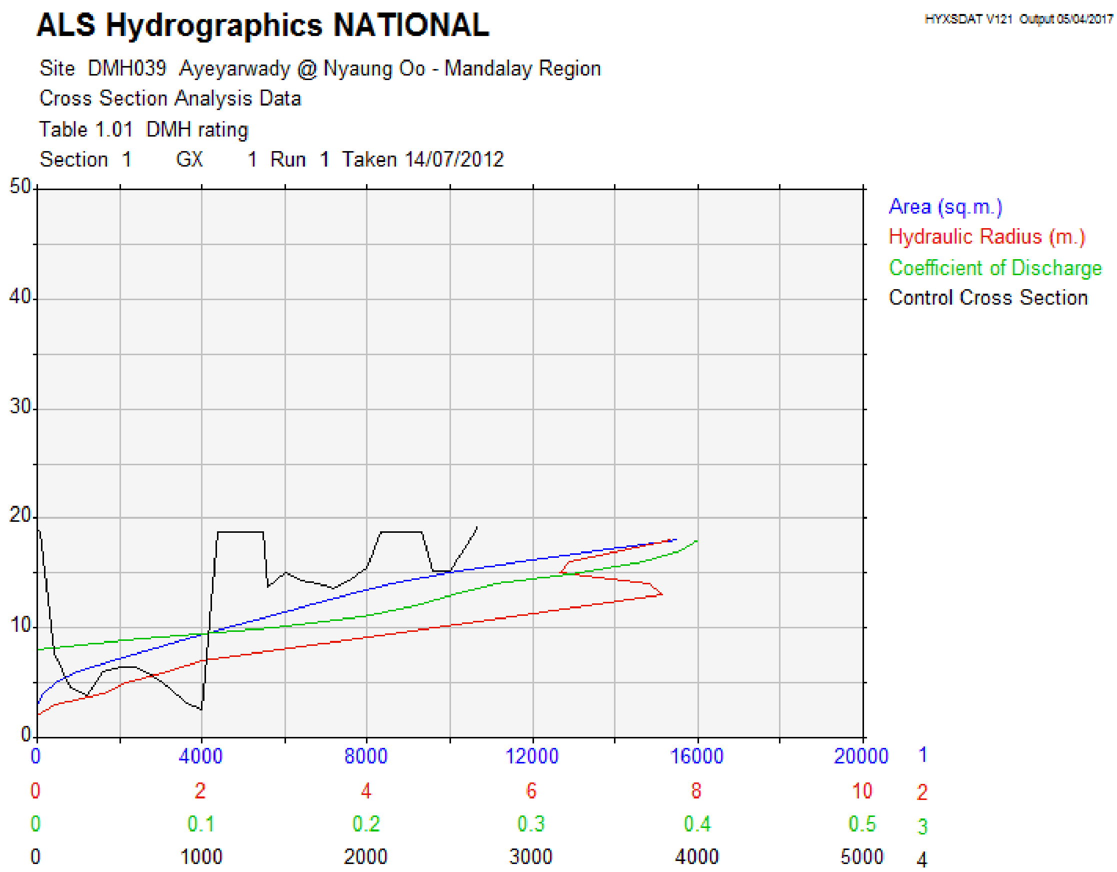
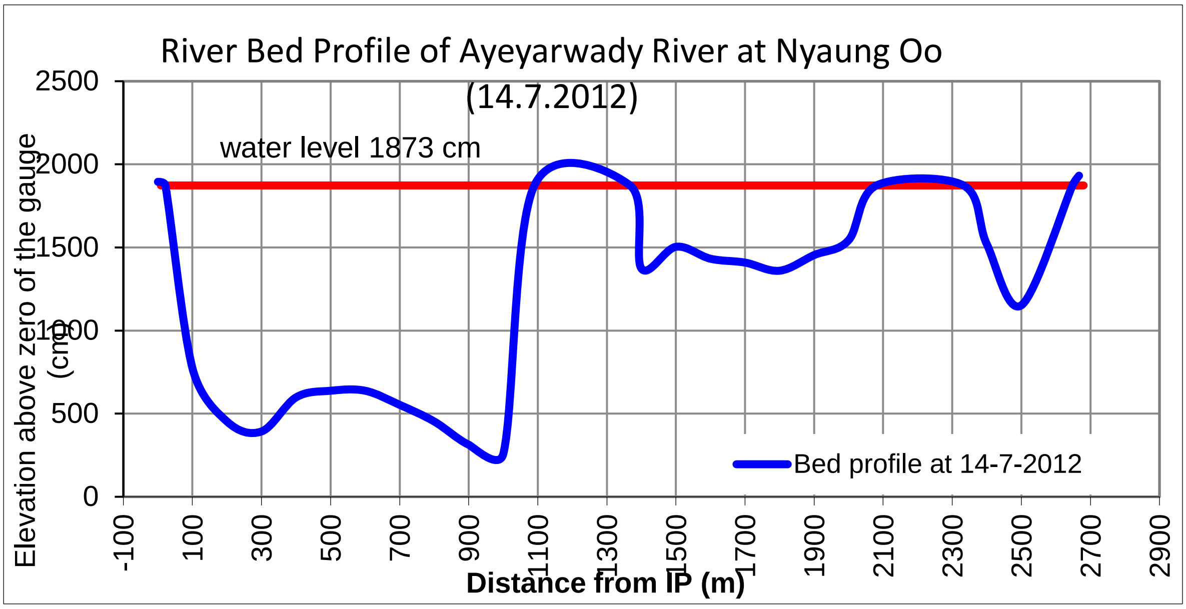
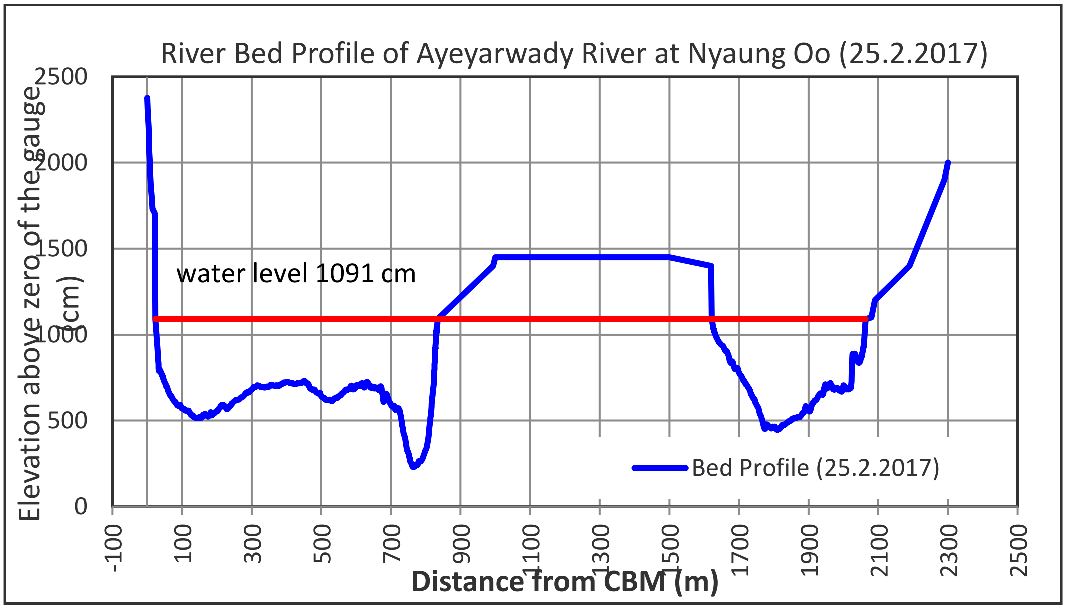


Figure 46: Nyaung Oo – original cross-section analysis

Figures 47 & 48 below show the difference in the area tables between July 2012 and February 2017. The figures below show that although the cross-section details were not recorded at the exact location they were recorded close enough to show that the stream bed has changed considerably in the last three years.





Figures 47 & 48: Sagaing - observed change in cross section between June 2010 and February 2017

To be able to compare like with like, it is essential that the cross-section / gauging locations be clearly recorded for perpetuity.

Based on the gaugings, the new area table, the new hydraulic radii and the derived coefficients of discharge (K), Figure 49 below indicates how the existing coefficients of discharge for the existing rating was interpolated to suit the new hydraulic conditions of the site. This is the basis of the newly derived rating table.

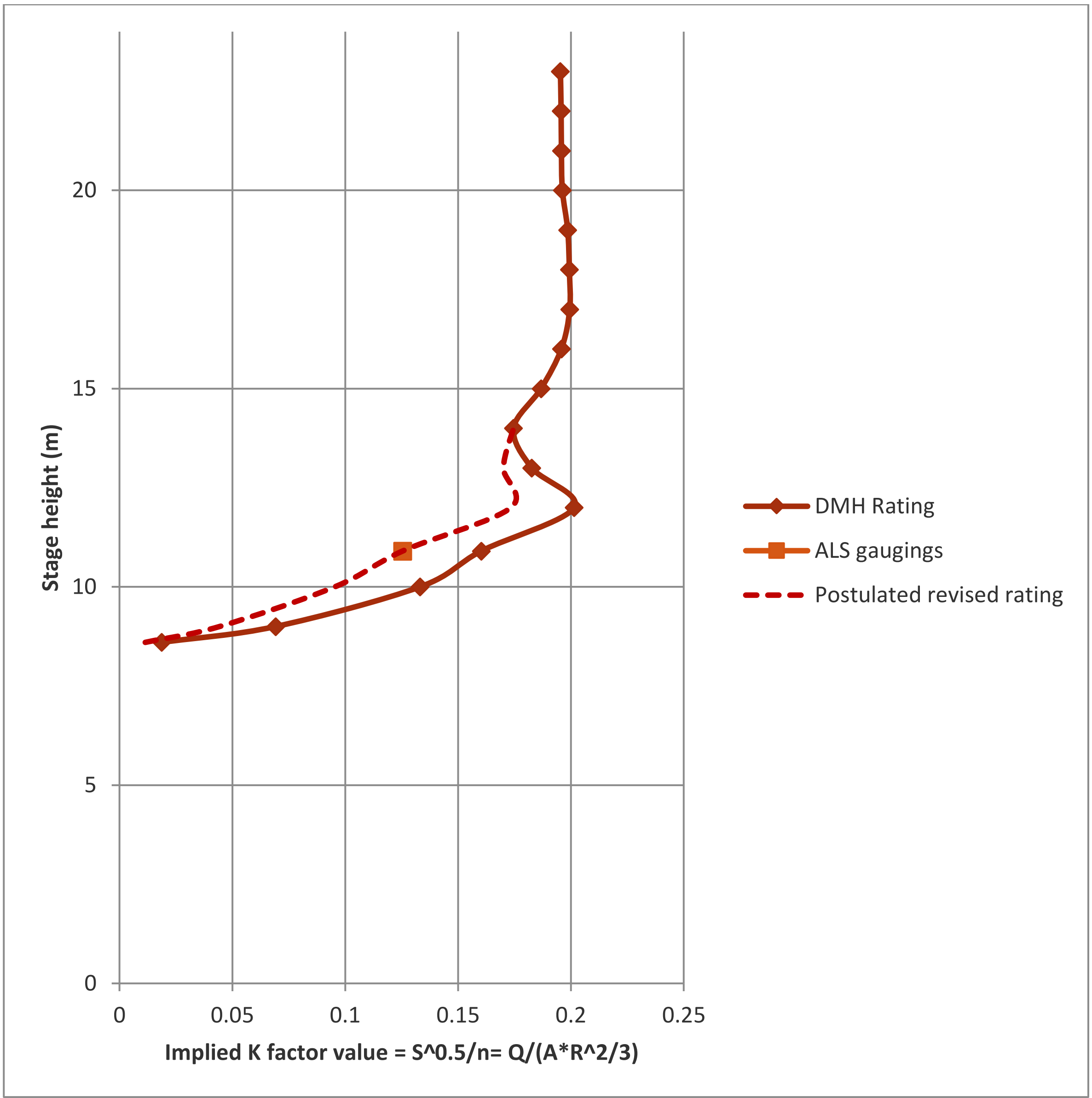


Figure 49: Nyaung Oo - observed and modified K factor values for rating table modification

The rating table was only modified below 14 metres for several reasons:

- The K values start to plateaux at approximately 14 metres
- There was not enough gaugings at higher values to support any changes above 14 metres
- There seemed to be little change to the river profile above 14 metres

The resulting changes to the rating are indicated on the following two figures that show how the gaugings previously all plotted on the right (high) side of the curve whereas now the curve bisects the group of gaugings evenly, giving the gauging an acceptable level of bias.

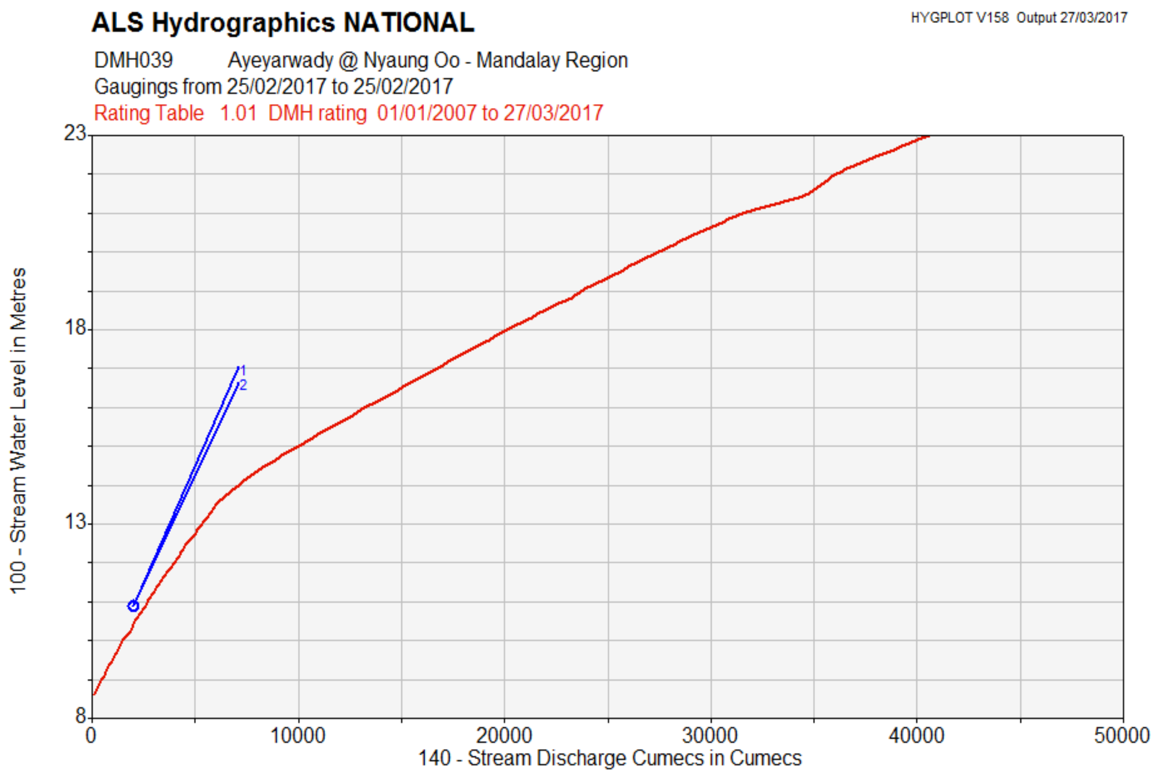


Figure 50: Nyaung Oo – February 2017 gauging results plotted against the original rating curve

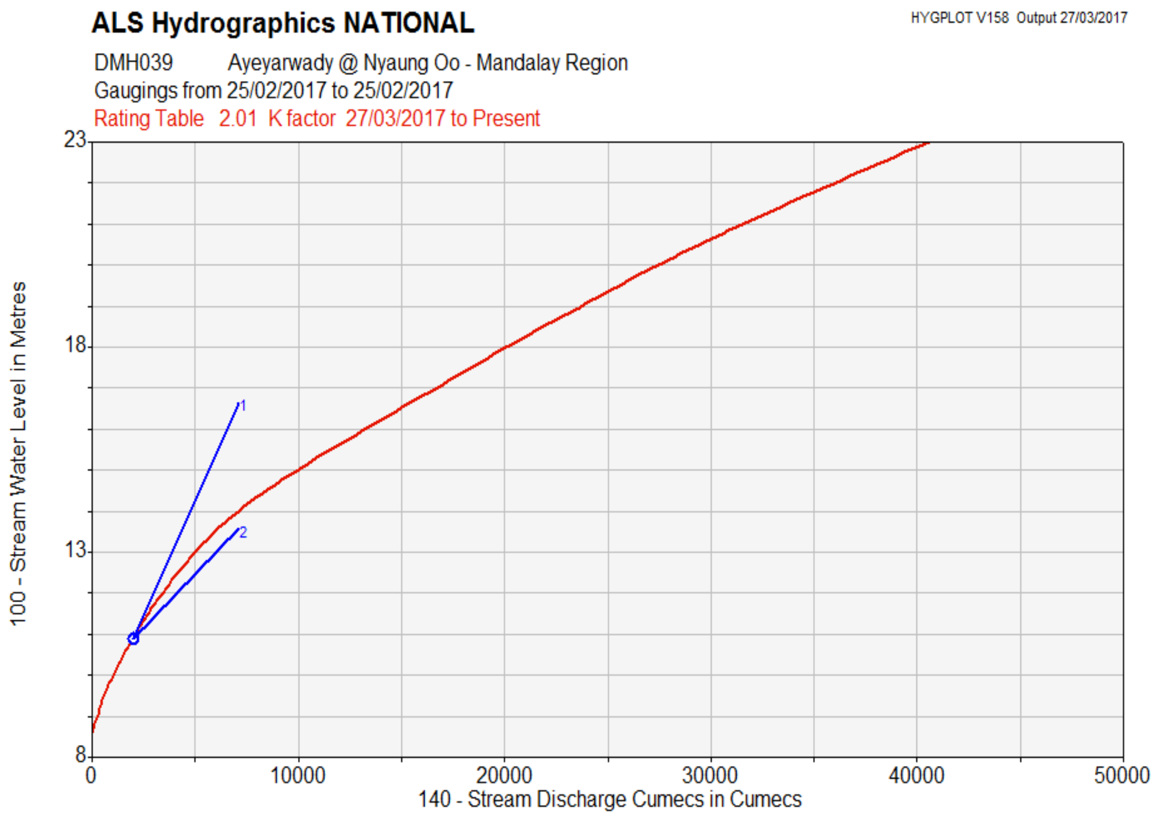


Figure 51: Nyaung Oo – February 2017 gauging results plotted against the modified K factor rating curve

7.5 Ayeyarwady River at Zalun

Figure 52: Zalun cross-section and gaugings were recorded at a different site from where the DMH take their measurements due the assumption that water was entering the stream at a nearby distributary

ALS Hydrographics NATIONAL

Ayeyarwady @ Zalun – Ayeyarwady

Rating Table 1.01 DMH047

Stage (m)	Area (sqm)	H.Rad. (m)
-5.000	1995.260	6.50
-4.000	2491.261	4.59
-3.000	3050.924	5.26
-2.000	3648.436	5.90
-1.000	4292.208	6.35
0.000	4995.863	6.79
1.000	5759.589	7.23
2.000	6611.771	7.17
3.000	7872.005	5.68
4.000	9339.362	6.01
5.000	10937.279	6.68
6.000	12756.370	6.88
7.000	14612.025	7.84
8.000	16474.633	8.82
9.000	18339.144	9.80
10.000	20205.487	10.8

ALS Hydrographics NATIONAL

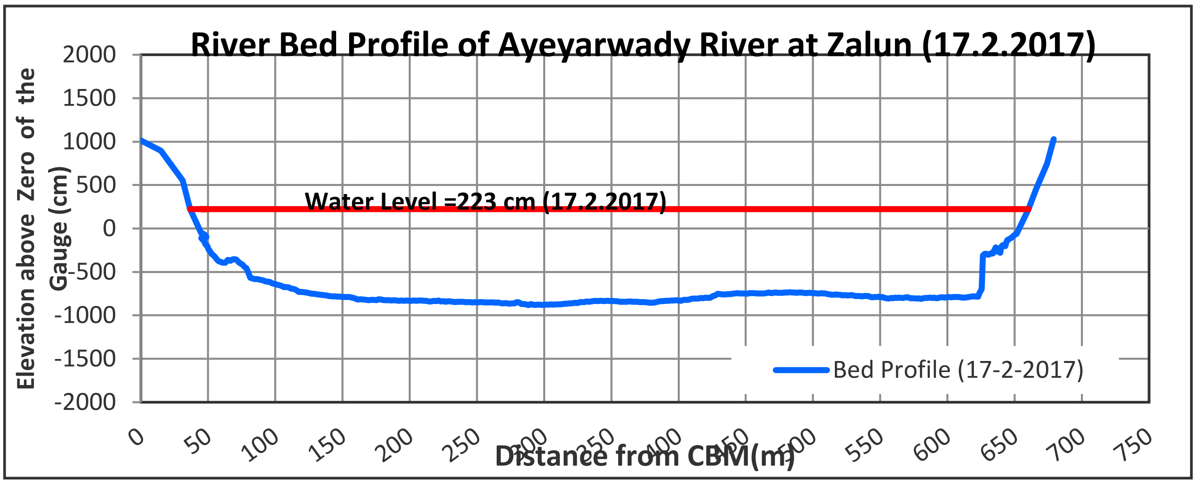
Ayeyarwady @ Zalun – Ayeyarwady

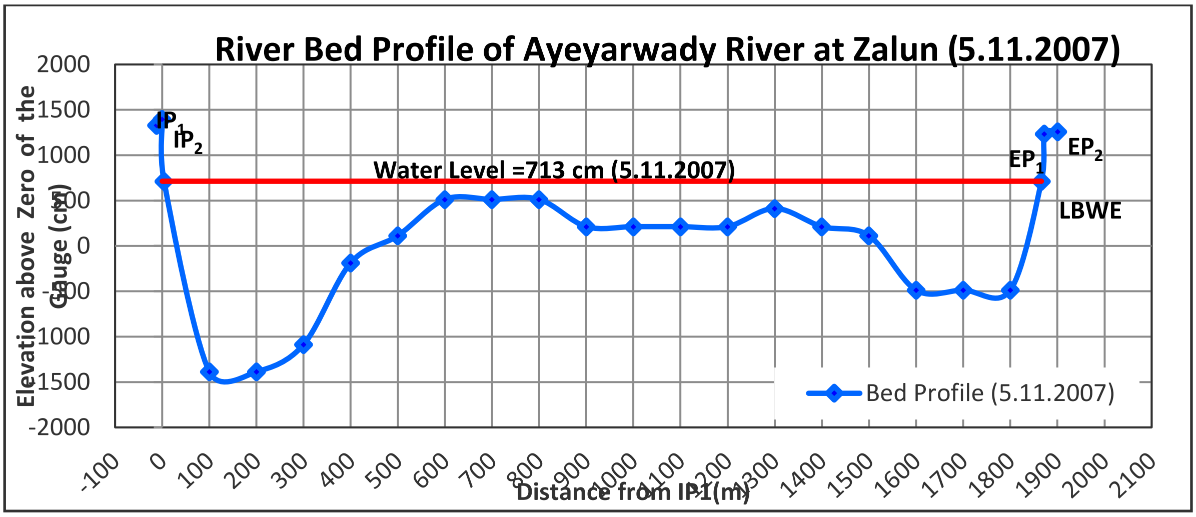
No Rating Table

Stage (m)	Area (sqm)	H.Rad. (m)
-5.000	1610.387	2.94
-4.000	2159.019	3.89
-3.000	2725.651	4.71
-2.000	3311.444	5.55
-1.000	3908.805	6.39
0.000	4514.429	7.25
1.000	5127.497	8.15
2.000	5746.565	9.04
3.000	6371.211	9.95
4.000	7000.141	10.8
5.000	7633.282	11.7
6.000	8271.156	12.6
7.000	8916.069	13.4
8.000	9568.298	14.3
9.000	10227.154	15.1
10.000	10896.763	15.7

Tables 27 & 28: Katha old area rating on the left; new area rating is on the right

Figures 53 & 54 show the difference in the area tables between July 2015 and February 2017. The figures below show that although the cross-section details were not recorded at the exact location they were recorded close enough to show that the stream bed has changed considerably in the last three years





Figures 53 & 54: Zalun – observed change in cross-section over time Note: Not the same horizontal scale

To be able to compare like with like, it is essential that the cross-section / gauging location be clearly recorded for perpetuity

Based on the gaugings, the new area table, the new hydraulic radii and the derived coefficient of discharge (K) Figure 54 below indicates how the existing coefficients of discharge for the existing rating was interpolated to suit the new hydraulic conditions of the site. This is the basis of the newly derived rating table.

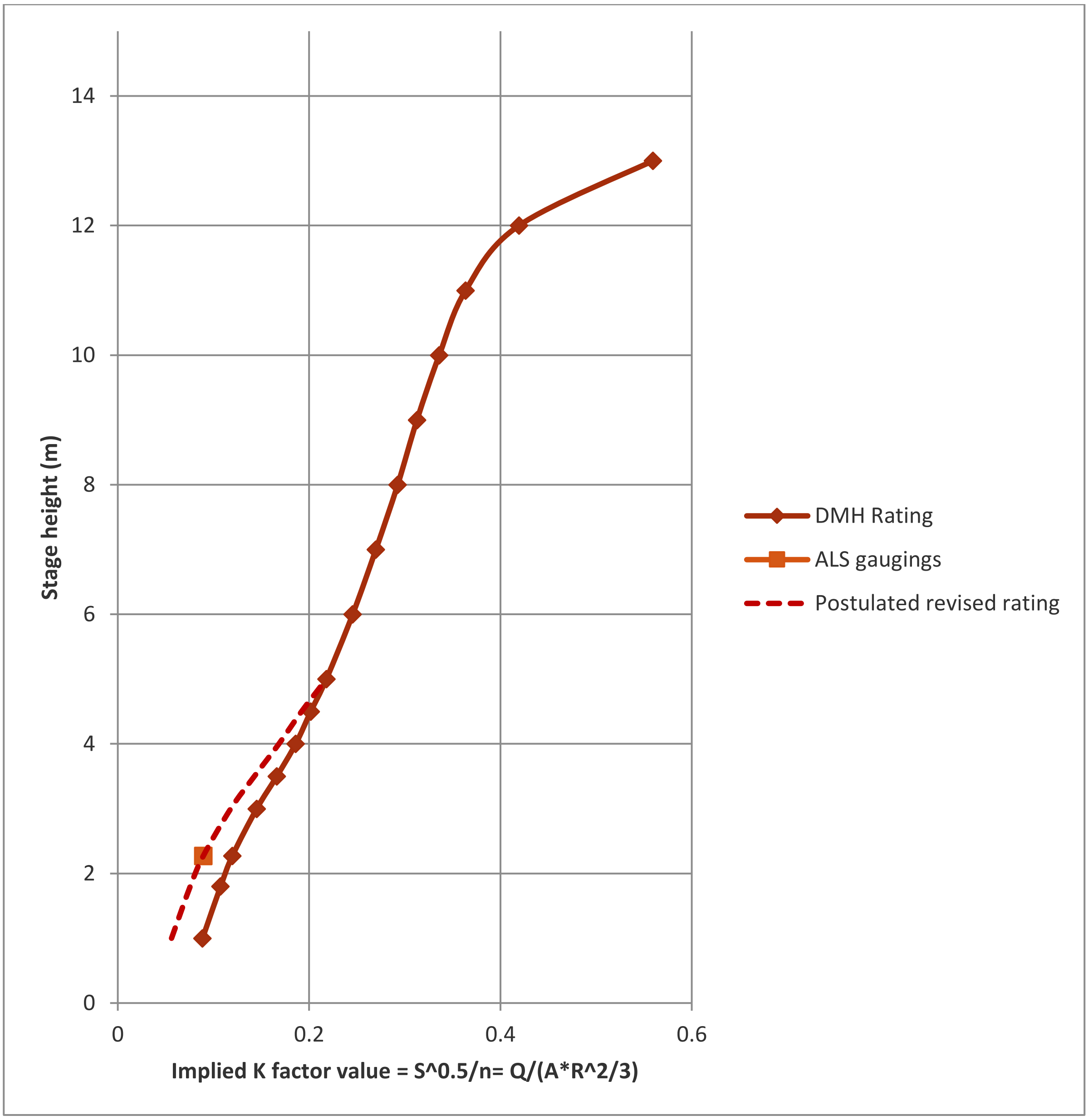


Figure 54: Zalun - observed and modified K factor values for rating table modification

The rating table was only modified below 5 metres for several reasons:

- There is an inflection of plotted K values at approximately 5 metres
- There was not enough gaugings at higher values to support any changes above 5 metres
- There seemed to be little change to the river profile above 5 metres

The resulting changes to the rating are indicated on the following two figures that show how the gaugings previously all plotted on the right (high) side of the curve whereas now the curve bisects the group of gaugings evenly, giving the gauging an acceptable level of bias.

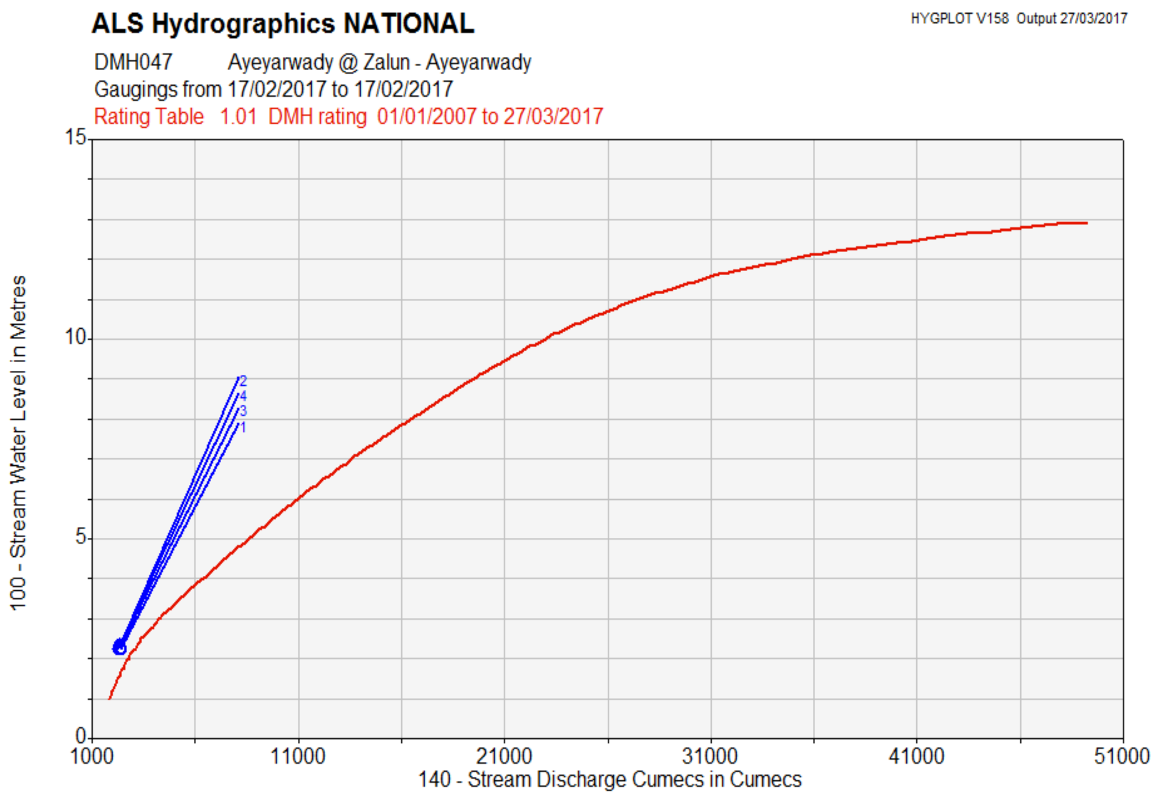


Figure 55: Zalun – February 2017 gauging results plotted against the original rating curve

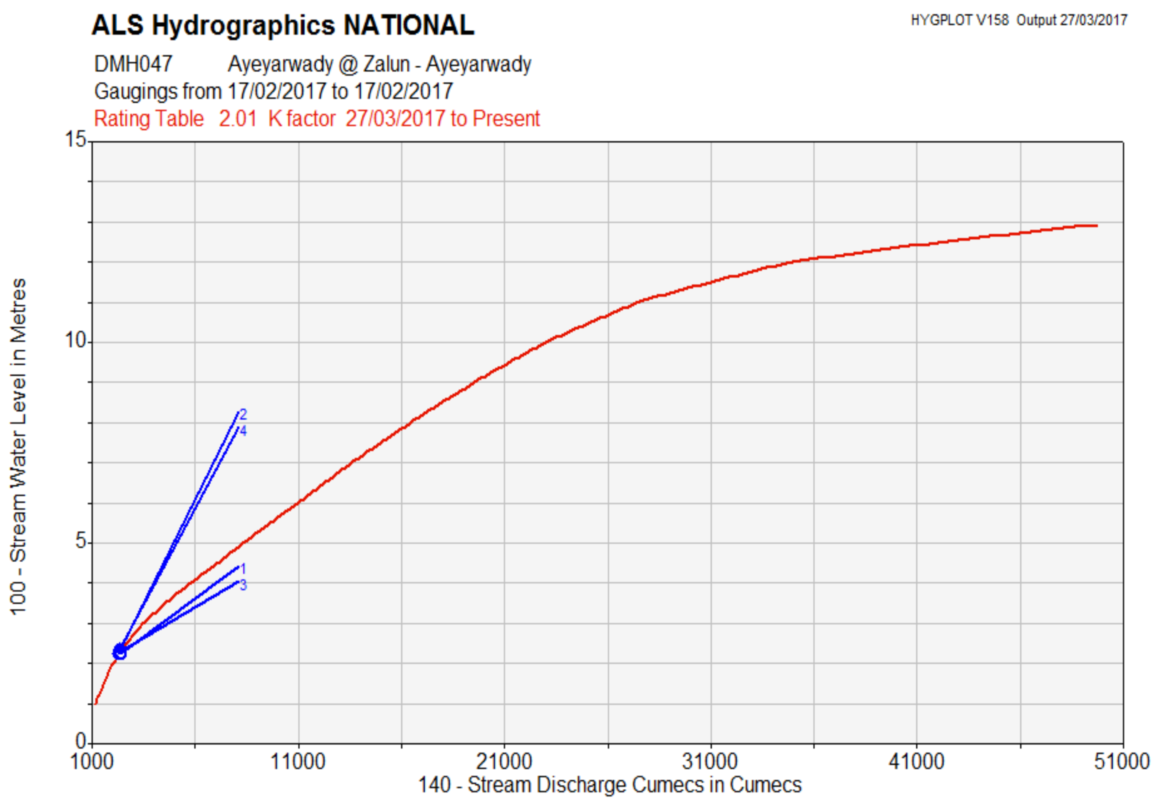


Figure 56: Zalun – February 2017 gauging results plotted against the modified K factor rating curve

Additional hydrographic works to consider for a tidal site

A river monitoring site affected by downstream tide levels cannot have a unique rating relationship. Different monitoring and management approaches would be required to adequately monitor in such a way to give freshwater discharge at the site, independent of tide effects.

As a minimum at least two level sensors would be needed (to continuously monitor water surface slope as well as depth), and/or a velocity sensor located at a carefully chosen position to act as a velocity indexing position- to calculate average cross section velocity in all tidal flow conditions.

There is an ISO which describes how to design monitoring for and manage such a site: ISO 2425 (2010) - *Hydrometry – Measurement of liquid flow in open channels under tidal conditions*. A summary of its contents gives some idea as to what monitoring changes may need to be considered:

> *ISO 2425:2010 provides a summary of recommended methods for the determination of liquid flow in tidal channels, special consideration being given to those techniques that are either unique to or particularly appropriate for application under tidal conditions, including treatment of uncertainties.*
>
> *Reference is also made, where appropriate, to methods for the determination of flow in non-tidal channels, but attention is drawn to their limitations with respect to practicality and/or uncertainty.*
>
> *ISO 2425:2010 does not describe alternative methods, such as the use of weirs, flumes, dilution gauging, salt velocity and floats, although they might be suitable under certain conditions, especially where the effect of tides only impedes and does not stop or reverse the passage of stream flow. These methods are described in detail in other International Standards.*
>
> *ISO 2425:2010 specifies two types of technique: techniques for single measurements of tidal flow; techniques for continuous measurement of tidal flow.*
>
> *Annex A specifies the cubature method of measurement. Annex B specifies methods for the determination of flow under tidal conditions, and Annex C gives an example of the computation for a single vertical. Similar computations are possible for other verticals. Annex D describes the determination of tidal flow using an acoustic Doppler velocity meter.*

The other useful sources of guidance for managing tidal site ratings is from USGS:

- OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM NO. 2010.08
  SUBJECT: Processing and Publication of Discharge and Stage Data Collected in Tidally-Influenced Areas
- USGS Hydratools Manual Version 1.0 (2005)— Documentation for a MATLAB®-Based Post-Processing Package for the Sontek Hydra - USGS Pacific Science Center Open-File Report 2005-1026

8 Conclusions

8.1 Summary

The aim of the rating review was to objectively assess the accuracy of the present ratings at five pilot sites, to confirm that high morphology is a major factor in shifts in ratings and to provide recommendations on how to address the issues of data and rating accuracy. This was accomplished by taking a “snap-shot” of the site and its condition on one day. Consequently this review must be judged on the scope that the Activity 1 team had to work with. The steps involved gauging the five sites until the Activity 1 team were confident the gauging results were accurate and of a high quality. The cross-section profile was obtained at each of the gauging locations and compared this with the previous cross-section data that was given to the Activity 1 team from the DMH. The Zalun and Katha cross-sections were not surveyed at the same location as the DMH cross-section to accommodate for the present stream conditions. However it is acknowledged the cross-sections and gaugings should be taken at the same locations whenever possible for continuity and synergy purposes.

Through characterising the uncertainty, the bias and the sensitivity of the channel rating and cross-section the Activity 1 team was able to asses that all sites needed rating adjustments at the heights they were gauged. There was a postulated adjustment to the existing rating curves at the following sites:

Chindwin River at Kalewa: The present rating table was unacceptable due to cross-section changes and consequently the rating adjusted below 8 metres

Ayeyarwady River at Katha: The present rating table was unacceptable due to cross-section changes and consequently the rating adjusted below 4 metres

Ayeyarwady River at Nyaung Oo: The present rating table was unacceptable due to cross-section changes and consequently the rating adjusted below 14 metres

Ayeyarwady River at Zalun: The present rating table was unacceptable due to cross-section changes and consequently the rating adjusted below 5 metres

Sagaing was tested using the rating given by the DMH and the rating curve discovered at the gauging station. The rating found at the gauging station passed all tests, whereas the rating given to the Activity 1 team did not. This raised concerns about documentation and record keeping.

To improve SOBA understanding and improve the quality of hydrological baseline data, there must be a commitment to the ongoing gauging and the regular review of rating tables at critical stream monitoring sites.

Rating reviews should be done at least annually at all of the pilot sites and by inference, all gauging sites. Other rating reliability improvements may include relocating gauging stations to a more stable location where geomorphology is less active therefore making the review process less acute.

There seems to be a commitment to ADCP gauging capability and this is to be commended however a root and branch review in the gauging program, in-house rating review regime, competency training and quality assurance techniques would be recommended. The Activity 1 team has made inroads in this regards by developing a separate document that is available to the HIC, DMH and DWIR stakeholders.

The document titled ***Field Guide: Operation and maintenance of hydrometric monitoring sites*** was presented to the HIC and DMH 31/03/2017.

8.2 History

It is recommended that the hydraulic “history” of the all sites need investigation to confirm (or otherwise) the magnitude and direction of the postulated change in discharge rating, for example by asking the following:

- Are measurements taken in the same location and by the same method?
- Has the channel been subject to substantial change or debris build-up or removal?
- Is there a downstream feature such as a natural gorge or weir or river crossing which has been subject to increase or decrease?
- Do DMH’s own gaugings confirm the need to shift the rating, and if so, can the hydrodynamic model be recalibrated to match the gaugings and used to redefine the site rating?

The results of this kind of investigation will assist with the weighting of the need for rating reviews at all DMH sites of interest and be the basis of repeatable measurement techniques. Ideally the DMH should concentrate on the sites that offer the most stable locations for level to discharge relationships. If hydrometric sites are primarily used for navigation or flood warning but are not suitable for rating curve development then this should be accepted.

Of the five pilot sites the following is advised. (*See explanations below)

Criteria	Kalewa	Katha	Sagaing	Nyaung Oo	Zalun
Suitable for reliable rating table development	Yes	No *1	Yes	No *2	Yes *3
Move ADCP gauging site from present location	Yes *4	N/A	No	N/A	No
Site suitable for telemetry installation and general modernisation upgrade	Yes	No *5	Yes	Yes *6	No *7

Table 29: Pilot site recommendation summary

1. Katha has high morphology rates that would make the rating between level and discharge in a constant state of flux. It is recommended that the upstream site of **Shwegu** be considered for flow data in the region
2. Nyaung Oo also has high morphology rates that would make the rating between level and discharge in a constant state of flux. This site is suitable for flood warning. It is recommended that the downstream site of **Chauk** be considered for flow data in the region
3. Zalun should have hysteresis rating developed to account for tidal influence (see points 8.4 & 8.5). Alternatively the upstream site of **Pyay** could be used for flow data in the region
4. The present gauging site is too close to the confluence and a major bend in the Chindwin River. A location 4 km upstream that would appear to be stable and would offer continuity of measurement (see figure 57)
5. Katha has no infrastructure such as a bridge to provide support any radar stream level sensing equipment

6. Nyaung Oo has only limited useable infrastructure at the water treatment works
7. Zalun also has no infrastructure such as a bridge to provide support any radar stream level sensing equipment.

Figure 57: Ideal gauging location in red

8.3 Gauges and benchmarks

Channel benchmarks or CBMs at the gauging sites seem to have no relationship to the indicated gauge zero of the gauge plates and the datum supplied. However they did al align with the gauge readings taken by the staff officer on the day that we visited the site. It is recommended that the gauge zeros, the piles and the CBMs be officially levelled and tied into a uniform datum nationally. This will minimise the likelihood of errors based around the incorrect gauge height being attributed to future gaugings and will assist in the checking and hence the reliability of the gauge heights derived from the piles. The marking of the piles should be improved as signs of paint deterioration was evident. Gauge plates should be established if there is a suitable piece of infrastructure at the site.

Figure 58: (Left) Pile at Katha that was difficult to locate

Figure 59: (Right) International standard gauge plates should be established wherever possible

8.4 "Loop rating" hysteresis considerations for higher (and tidal) flows

The gaugings reviewed were all during steady low flow conditions. No attempt could be made to review the accuracy of the higher flow portions of the DMH rating tables, as there were no gaugings taken in this range.

Given the gentle bed slopes of the river and the likely rapid rise and fall of flow hydrographs from large storm events, it is highly likely that all 5 sites are affected by loop rating (hysteresis) effects, to various extents. Note that each flow event will have its own unique loop. If this proves to be the case at these sites, then a single level sensor and a single steady state rating table will not be sufficient to give accurate discharges.

ISO 1100 (2010) has the following information and advice on this phenomenon:

> *The stage-discharge relationship for a gauging station gives the value of the normal discharge, i.e. the steady-flow discharge, for a given stage. The discharge for a particular stage can, for some rivers and streams, be greater than the normal discharge during rising stages and less than normal during falling stages because of differences in the water surface slope. This effect is known as hysteresis, or a loop rating curve. It is most pronounced for mildly sloped rivers where dynamic flow conditions are imposed by a passing flood wave.*
>
> *For gauging sites where the hysteresis effect is severe, instantaneous values of the discharge determined from the steady-state rating curve can be significantly different from the true discharge. For these sites, it* ***might be necessary*** *to use auxiliary equipment to supplement the gauge height record in order to determine discharges accurately. A twin-gauge approach utilizing the stage-fall-discharge relationship can be used (see ISO 9123). Alternatively, a twin-gauge approach using an unsteady-flow model could be used (see ISO/TR 11627). In other situations, it might be feasible to use a velocity index relationship (see ISO 15769).*
>
> *If the hysteresis effect is not severe, but of sufficient magnitude to need correction, it might be possible to use a single-gauge record of the stage in conjunction with the rate of change in the stage to compute the discharge. For certain conditions, it is possible to compute the true discharge, Q, of an unsteady flow from the steady-state discharge, Qo, by using the following equation…*
>
> (The standard then gives the equation and explains how to use it- based on just the level sensor at the site, and the rate of rise or fall of the hydrograph.)

To determine if these sites are significantly affected by hysteresis then either or both of two methods can be used:

- Method A- ADCP gaugings to be captured from start to finish of a large flow event, from its initial rise, its peak, and then its recession. These gaugings can then be plotted against stage, and the loop will be obvious or not.
- Method B- use a hydrodynamic model run for one or several high flow hydrograph events, and extract the depths and discharges from each model node which equates to a monitoring station, then plot the model routed depth and discharges against each other, and observe the presence of a rating loop or not.

Method A is more direct and reliable. Method B is less reliable, but is a good first step to evaluate if it might be worth the expense of doing a full gauging method A - if the model does show significant loop rating effects.

8.5 Additional hydrographic works to consider for a tidal site

A river monitoring site affected by downstream tide levels cannot have a unique rating relationship. Different monitoring and management approaches would be required to adequately monitor in such a way to give freshwater discharge at the site, independent of tide effects.

As a minimum at least two level sensors would be needed (to continuously monitor water surface slope as well as depth), and/or a velocity sensor located at a carefully chosen position to act as a velocity indexing position- to calculate average cross section velocity in all tidal flow conditions.

There is an ISO which describes how to design monitoring for and manage such a site: ISO 2425 (2010) - *Hydrometry – Measurement of liquid flow in open channels under tidal conditions*. A summary of its contents gives some idea as to what monitoring changes may need to be considered:

> *ISO 2425:2010 provides a summary of recommended methods for the determination of liquid flow in tidal channels, special consideration being given to those techniques that are either unique to or particularly appropriate for application under tidal conditions, including treatment of uncertainties.*
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> *Reference is also made, where appropriate, to methods for the determination of flow in non-tidal channels, but attention is drawn to their limitations with respect to practicality and/or uncertainty.*
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> *ISO 2425:2010 does not describe alternative methods, such as the use of weirs, flumes, dilution gauging, salt velocity and floats, although they might be suitable under certain conditions, especially where the effect of tides only impedes and does not stop or reverse the passage of stream flow. These methods are described in detail in other International Standards.*
>
> *ISO 2425:2010 specifies two types of technique: techniques for single measurements of tidal flow; techniques for continuous measurement of tidal flow.*
>
> *Annex A specifies the cubature method of measurement. Annex B specifies methods for the determination of flow under tidal conditions, and Annex C gives an example of the computation for a single vertical. Similar computations are possible for other verticals. Annex D describes the determination of tidal flow using an acoustic Doppler velocity meter.*

This was applied recently by Justin Stockley of Xylem Analytics to a river in Malaysia at a tidally affected monitoring site, to separate the freshwater flow from the tidal affected levels and velocities.

The other useful sources of guidance for managing tidal site ratings is from USGS:

- OFFICE OF SURFACE WATER TECHNICAL MEMORANDUM NO. 2010.08 SUBJECT: Processing and Publication of Discharge and Stage Data Collected in Tidally-Influenced Areas
- USGS Hydratools Manual Version 1.0 (2005) — Documentation for a MATLAB® - Based Post-Processing Package for the Sontek Hydra - USGS Pacific Science Center Open-File Report 2005-1026

8.6 Data management

The accuracy of a monitoring station is dependant not only on having properly maintained and calibrated equipment. It also requires heavily on additional information that may not necessarily be automatically recorded. The purpose of metadata is to describe factors contributing to the accuracy of the data collected. This description should remain with the data and does not change. It can be used to interpret, convert or process the resource data collected.

Hydrology time series data and the metadata associated with it should be stored in a hydrometric information and data management system. Commercially available examples include:

Hydstra from Kisters - https://kisters.com.au/hydstra.html

Aquarius from Aquatic Informatics - http://aquaticinformatics.com/products/aquarius-time-series/

ALS-Hydrographics use both systems and would recommend either. Presently in Myanmar this type of information is stored in documents, as images or related items that exist in some other native environment. This is not conducive for secure, usable and reliable data management.

Data management will be especially important when data is downloaded from a digital data logger at a field location. The associated metadata forms the basis to determine the quality of the hydrometric data recorded. A data management system will provide perpetuity, continuity, reliability and usability of all facets of hydrometric data collected.

It is understood that data management capability and improvement will come under the auspices of AIRBM Component 2.

9 Recommendations

Overview

A continuation of rating table reviews should take into account the entire data life cycle of the hydrometric data collected for water level and flow. As all data is related and errors will compound.

The sites in the Lower Ayeyarwady (Zone 4) should be targeted where it is presently thought that water is exiting and re-entering the system. This proposal would clarify if this phenomenon is truly happening or it is a misnomer based on rating table inaccuracies. It also allows for continued capacity building and skills and knowledge reinforcement in critical areas for the appropriate staff members of the HIC, DMH and the DWIR.

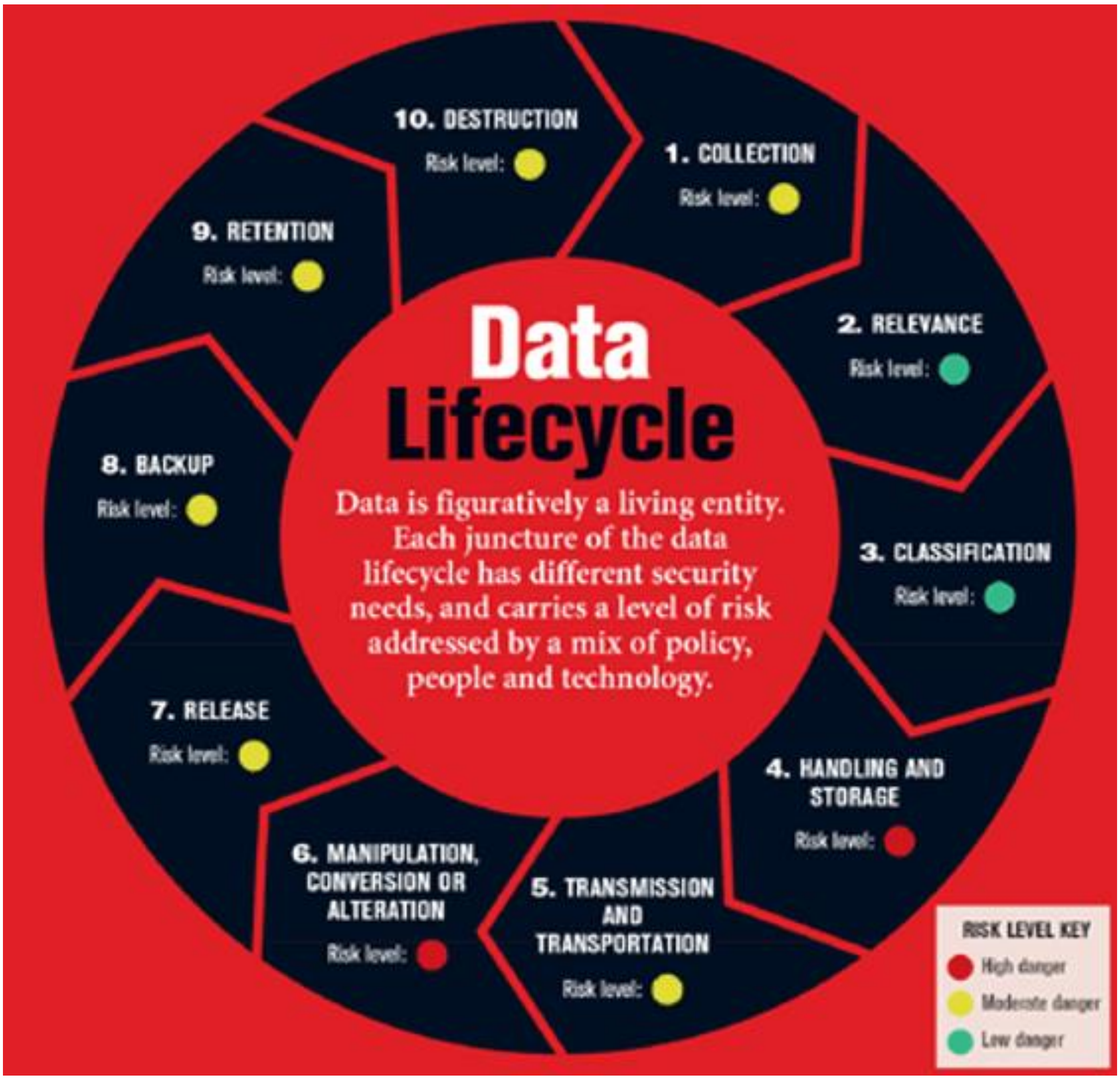

Figure 61: Data life cycle

The following is considered to be key to continuing the rating reviews for the entire Ayeyarwady Basin, but especially the sites in the Lower Ayeyarwady for the investigation into the present water balance discontinuity phenomenon.

9.1 Rationalise flow monitoring stations

a. Determine and advise on which of the 70 DMH sites are of the most important for flow and water resources information through a desktop review for rationalisation purposes

b. Ascertain the suitability of each of the important sites and develop a hierarchy for ranking as to which sites are prioritised to have their ratings reviewed

9.2 Review and upgrade sites in the Lower Ayeyarwady

a. Determine which of the sites in the Lower Ayeyarwady need to have their rating reviewed due to water balance discrepancies

b. Gauge, survey and review the cross-sections and ratings at the targeted sites

c. Establish gauge plates where possible at the targeted sites and tie them into the appropriate national datum

9.3 Review and mentoring of complete data live cycle

a. Accompany the DMH observation officers when the data is collected in the field for level to flow rating reviews at the sites in the Lower Ayeyarwady where there are discrepancies in the continuity of the water balance

b. Assess and advise on the present data collection techniques, storage, processing, manipulation and dissemination by the DMH using their own equipment

c. Review, assess and advise on the rating review and maintenance protocols of the DMH

9.4 Capacity building

a. Establish gauge plates at the Lower Ayeyarwady gauging stations visited. Simultaneously train DMH staff to continue with this program across all monitoring sites wherever deemed suitable

   i. Surveying skills and knowledge development

   ii. Documentation skills and knowledge development

   iii. Gauging station establishment skills and knowledge development

b. Conduct a water balance review at the sites of interest in the lower Ayeyarwady where it thought there is water leaving the river and re-entering downstream through ADCP gaugings, cross-section surveying and data management processes

   i. ADCP gauging skills and knowledge development

   ii. Rating table review skills and knowledge development

   iii. Open channel hydraulics skills and knowledge development

c. Conduct formal competency based training in ***Apply principles of open channel hydraulics*** and ***Develop and maintain ratings*** through a combination of workplace assessment and format training through a webinar environment[3]

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[3] The competency based training recommended units of competency are from the Diploma of Water Industry Operations under the Australian National Water Training Package NWP50715. Information is available at: http://training.gov.au/Training/Details/NWP50715

10 Citations

10.1 Rating review references

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Data life cycle - image available at: http://searchsecurity.techtarget.com/magazineContent/Data-Lifecycle-Management-Model-Shows-Risks-and-Integrated-Data-Flow