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Rehabilitation of Streams Receiving Inter-Basin Transfers - NSW North Coast

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SUMMARY: On the NSW North Coast, water has been transferred for 74 years from the Nymboida River into the Orara River, via Goolang and Blaxland Creeks, for hydro-electric power generation. The rehabilitation and maintenance of channel stability downstream from the discharge outlet is a condition of the operator's license. To date, erosion control works have been site-specific bank stabilisation without an understanding of the underlying geomorphic processes. As a result, most of these works have become ineffective. In an effort to make future erosion control works more successful, the geomorphic behaviour of the creeks was determined.

Historical records, plans, anecdotes and aerial photographs indicate major changes to channel form in all three streams. This was confirmed by field evidence and a detailed long profile. Seven types of stream behaviour were identified in the study reach. Goolang and Blaxland Creeks have experienced extensive bed erosion and channel widening. The sediment from the erosion has filled pools in the Orara River. These geomorphic responses to the interbasin water transfer are related to the factors of slope, bed/bank material, vegetation and human activities.

A rehabilitation and maintenance plan was developed that is based on the geomorphic behaviour of the streams. It covers 40 km of stream length, from the discharge outlet in Goolang Creek, along Blaxland Creek and into the Orara River. The types of works recommended in the plan use the behaviour-determining factors to help each stream to recover its equilibrium. The works must also rehabilitate the riverine environment while providing for white-water canoeing on the power station releases.

MAIN POINTS

- the geomorphic response of streams receiving inter-basin transfers can be complex due to local variations in slope, bed/bank material, vegetation and human activities.
- rehabilitation works must be designed to utilise the local variations to change the stream behaviour to restore equilibrium or at least reduce erosion rates to "natural" rates.
- rehabilitation of stream structure in Goolang and Blaxland Creeks to reduce erosion rates will benefit in-stream habitat diversity and ecological function.
- the rehabilitation works planned for Goolang and Blaxland Creeks streams have also been designed to enhance the riverine environment and provide for white-water canoeing.

1. INTRODUCTION

Since 1924, water has been extracted from the Nymboida River, a major tributary of the Clarence River, NSW, for the generation of hydro-electricity. The water from the Nymboida is piped over a divide into a hydro-electric power station (North Power) on a small stream at a much lower elevation called Goolang Creek. It flows down this creek into Blaxland Creek and eventually into the Orara River which is a major tributary of the Clarence River (Figure 1).

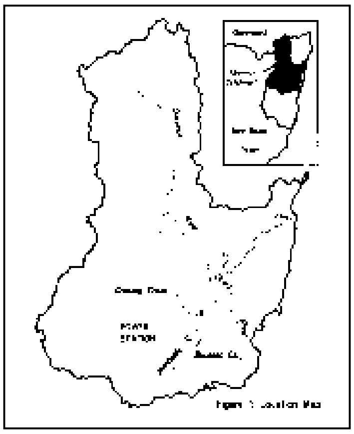

Figure 1 : Location Map

The power station operation is licensed by the Department of Land and Water Conservation (DLWC). A condition of the license is that North Power must maintain channel stability on Goolang and Blaxland Creeks. To comply with their license, North Power has contracted Clarence River County Council (CRCC) to undertake erosion control works on their behalf since 1967. These works have not been very successful in controlling extensive accelerated bed and bank erosion on the two creeks. The channel has become deeply incised, over-wide and has lost the previous pool-riffle sequence along much of its length. Landholders continue to lose land to erosion. Large quantities of sediment from the accelerated erosion have been depositing in the Orara River and filling pools. During periods of no water discharge from the power station, much of the Orara River flows below these sand deposits. These changes to channel form also have negative effects on the stream ecosystem and in-stream water storage. This paper describes the results of a project (Department of Water Resources 1991; Broderick and Outhet 1998) to determine why the works failed and to determine what works, if any, would be better suited to the situation. Designing erosion mitigation works is a core activity of DLWC.

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2. HISTORICAL EVIDENCE OF CHANNEL CHANGES

Channel changes in Blaxland Creek were investigated using aerial photographs, past and recent surveys, historical reports and files, geomorphic indicators and anecdotal evidence.

Aerial photographs taken in 1994 were compared with aerial photographs taken in 1973 (Bolton and Associates, 1973). The 1973 set preceded the large floods of 1974, during which bridges were damaged and/or destroyed and much erosion of Blaxland Creek took place. The 1973 photos clearly show extensive bank erosion, channel widening, lateral channel migration along the length of Blaxland Creek and aggradation of the Orara River. Evidence of bed lowering is more difficult to obtain from aerial photographs. Bank erosion on the inside bends is an indicator of bed degradation. While this was common along Blaxland Creek in 1973, it is difficult to determine from aerial photographs whether channel widening or channel incision was the primary cause. Comparison of the photos revealed the amount of regeneration of riparian vegetation that occurred between 1973 and 1994. The obscuring effect of riparian vegetation limited the use of the 1994 aerial photographs. However, they show that the extent of active bank erosion was greatly reduced in some reaches.

Historical files relating to Blaxland Creek were provided by North Power (Clarence River County Council 1967a) and the Department of Land and Water Conservation (Department of Water Resources 1991). Information was gleaned from these on individual erosion mitigation works and erosion complaints. Whilst limited in their use, they did provide an insight into where and when most of the erosion problems had been occurring.

1967 surveys of the extent of bank erosion along Goolang and Blaxland Creeks (Clarence River County Council 1967b) showed the degree of channel widening that took place prior to 1967 between 10 & 20 metres of land was lost on both sides of the creek for almost its entire length. Further erosion took place due to the formation of gully heads and nickpoints in tributaries of Blaxland Creek following channel incision and/or widening of Blaxland Creek. Whilst these surveys demonstrated the vast amount of land which was eroded, creek bed levels were not incorporated, preventing their use in comparing past and present creek bed levels.

Anecdotal evidence provided by local landholders was useful in confirming the timing and sequence of events as they related to river processes.

Extensive 1997 survey work, geomorphic analysis and inspection of old erosion mitigation works and bridges enabled Blaxland Creek bed levels of the mid to late 1970's to be estimated and compared to present day bed levels. Figure 2 is an example of the evidence of bed lowering. The long profile and the "hanging" erosion control mesh work shows that the creek bed lowered an average of 1.5 metres since 1974, except where solid rock or large gravel armour is present across the whole stream bed.

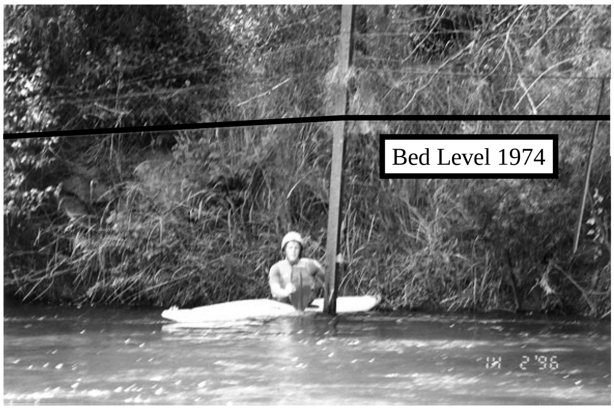

Figure 2: Hanging bottom cable of old mesh erosion control works indicating the amount of bed degradation since 1974.

It was assumed that the erosion control mesh works were designed so that the bottom cable was constructed at bed level. The present day height of the bottom cable was linked with major bedrock rapids to define the prior bed profile of the channel. These rapids are apparent on the 1973 aerial photographs. It was also assumed that the pool and riffle sequence prior to 1974 had a graded long sectional profile (concave in shape and steepening upstream) with local alluvial reaches having constant slopes and steep reaches only occurring at the bedrock rapids. This contrasts with a detailed long profile surveyed in 1997 which shows the location and extent of the bed lowering and the low nickpoints which are still present in the creeks.

All creek reaches studied are in the "throughput/transfer" part of the catchment where (before disturbance) sediment input naturally equals sediment output and the channels are naturally in a state of equilibrium with no significant overall degradation or aggradation.

3. STREAM BEHAVIOUR TYPES

The evidence of channel change discussed in the preceding section allows us to classify the behaviour of each separate reach of each stream. Fifteen reaches were identified as having one of the following behaviours:

1. Eroding Bed and Slumping Banks: The creek bed is continuing to erode, undermining the toe of the creek banks and causing bank failure and slumping.

2. Eroded Riffles and Stable Banks: The channel has increased significantly in width and the banks are no longer actively eroding. Erosion of riffles has

destroyed the pool and riffle sequence, the consequence of which includes shallow pools with increased flow velocities and decreased instream storage and aquatic habitat.

3. Channel Recovery: Formation of islands and bars in less steep reaches is building the bed level back up again and reinstating pools and riffles.

4. Recovered Channel: Creek bed and banks are stable and a pool and riffle sequence exists.

5. Bed Rock and Boulder Riffles: The presence of bed rock and large boulders has minimised bed erosion. The channel has widened but there is no longer active bank erosion.

6. Channel Aggradation: Large sediment deposits have filled in pools and raised bed levels. Consequences of this include loss of instream storage and aquatic habitat, decreased channel roughness and channel capacity and deflection of flows into banks by bars which have been stabilised by vegetation.

7. Incision of Previously Deposited Sediments: The river is cutting back down through the previously aggrading river bed. Sediments are slowly being moved through the river system.

In contrast to the above behaviours found in the channels receiving transferred water, both Goolang Creek upstream of the power station and Blaxland Creek upstream of the Goolang confluence appear to be in equilibrium. They are approximately one-third the size of the degraded channels, have long reaches with both banks covered with dense native vegetation and have well-developed pools and riffles. Table one presents a description of reach characteristics.

Table 1: Reach Characteristics of Blaxland and Goolang Creeks. Note that reach numbers progress upstream.

Reach	**Slope & Bed Material**	**Bankfull width/ depth (m)**	**Behaviour type**
1 Blaxland	0.001 sand & small gravel	32/6 11/<1	1.Eroded bed & slumping banks
2 Blaxland	0.0014 sand & very small gravel	50/6 15/<1	2.Eroded riffles & stable banks
3 Blaxland	0.0023 small gravels and sands	52/5 19/<1	3. Channel Recovery
4 Blaxland	0.0014 small gravels & sands	55/7.8 22/<1	4. Recovered Channel
5 Blaxland	0.0019 small gravels	52/7.8 21/<1	5. Bed rock & boulder riffles
6 Blaxland	0.0022 small and medium gravels	51/7 25/<1	6. Channel Aggradation
7 Blaxland	0.0017 small gravels	52/7 23/<1	7. Incision of Previously Deposited Sediments
8 Blaxland	0.0023 small gravels	43/5 35/<1	8.
9 Blaxland	0.0023 small gravels	40/5 17/<1	9.
10 Blaxland	0.0025 small gravels	35/6 17/<1	10.
11 Blaxland	0.003 bed rock & boulders	32/4 22/<1	11.
12 Blaxland	0.0034 small gravel	42/4.5 16/<1	12.
13 Blaxland	0.0022 large gravel & cobles	38/4.5 19/1-1.5	13.
14 Blaxland	0.0038 small gravel	35/3 19/1-1.5	14.
15 Blaxland	0.0027 large gravel & cobbles	32/5 20/1-1.5	15.

4. CAUSES OF CHANNEL CHANGE

The behaviour of the creeks upstream of the power station outflow indicates that the channel shape and dimensions had reached an equilibrium with the catchment runoff, channel bed/bank materials and vegetation before the start of the diversions. When the transfer of extra water (860ML/D maximum) into Goolang and Blaxland Creeks from the power station started, the high frequency discharge which forms the shape and size of channels was greatly increased. This has increased stream power (velocity, depth and turbulence) and caused accelerated erosion of any erodible materials in the stream bed and banks of Goolang and Blaxland Creeks. The erosion will continue until the channel has enlarged enough to reduce the stream power back below the level at which the bed and banks erode.

Parts of the bed of these two creeks have armoured; ie. the largest particles in gravel bed material have formed a "pavement" at the surface of the bed and protected the smaller particles underneath from being eroded. In reaches with a bedrock bed or gravel that has armoured easily, channel enlargement has occurred mainly by widening because the banks are usually more erodible than the bed. This process has not occurred in those reaches of Blaxland Creek that have small gravel and sandy bed material. In this case, the bed is more erodible than the banks due to its lack of compaction and cohesion. The bed will lower quite quickly by local scour and by "nickpoint" (low headcut or upstream-migrating riffle) retreat.

The main result of the bed lowering is loss of support for the banks and also exposure of bare material at the toe, unprotected by vegetation. The final result is collapse of all stream banks and an overall channel enlargement.

Another result of bed lowering has been the loss of riffles and/or the lowering of high riffles. This has caused a decrease in channel roughness, further accelerating the degradation process. It also has had the effect of reducing the number of low flow pools and/or their depth. These changes to stream structure have reduced in-stream habitat diversity and the opportunity for aquatic plants to establish.

5. PREVIOUS EROSION CONTROL WORKS

From the old files and reports, it is obvious that none of the information on stream behaviour and cause described above was considered when the 1960's and 1970's erosion control works were being designed. The following sections contain descriptions of these works.

5.1 Mesh work

"Mesh work" is a bank erosion control method that uses low chain wire fences to trap debris (DLWC Riverwise notes). This slows the flow near the bank, causing sediment deposition. Riverine vegetation planted between the fences then puts out new roots into the sediment, preventing it from moving in the next flow. This process repeats until the fences disappear under a well-vegetated bench that protects the toe of the bank from erosion. The method usually works well but not in situations where the bed is lowering. Where this happens, the fences are left hanging in mid-air and unable to trap debris and sediment. The vegetation component is destroyed. This is what happened on Blaxland Creek to the works installed in the early 1970's. The designers apparently did not realise that the creek behaviour was one of enlargement. Even if the bed was not lowering at the time, making the banks rigid with erosion control works would have caused the bed to erode so that the stream could expand to reduce flow energy back to pre-diversion levels.

5.2 Clearing of large woody debris

Extensive removal of large woody debris (snags) was done along Blaxland Creek between 1974 and 1978. The reason given at the time was "to increase flow capacity and thereby reduce velocities" (file note). This reveals a lack of understanding of natural channel hydraulics and stream behaviour.

Large woody debris (snags) is an important part of the hydraulics of stream channels and has a direct effect on the energy balance. The debris, along with live vegetation and the bed forms (bars, riffles, pools), increases the roughness of the channel and dissipates the energy of the flow, preventing it from eroding the bed and banks.

Removing debris from the channel decreases the roughness, often allowing the flow energy to increase above the erosion threshold. This results in channel enlargement by bank erosion and bed erosion (if the bed is not armoured). Large logs in the bed can also act as bed controls. That is, they prevent bed lowering by holding the bed material in place and by dissipating the energy of the flow releases adjacent to the bed.

It is likely that the program of extensive debris removal on Blaxland Creek between 1974 and 1978 accelerated the enlargement of the creek started by the power station releases.

6. OPTIONS FOR STRUCTURES TO REHABILITATE BLAXLAND CREEK

To restore the equilibrium of Blaxland Creek, structures are required to artificially dissipate the power station release flow energy so that it remains below the erosion threshold. Structures are also needed to raise the bed level to help support unstable banks and then to protect the toe of banks from erosion. These requirements can be met with bed raising structures, bank erosion control structures and debris reinstatement where appropriate. These are briefly described in the following paragraphs.

Detailed discussion on structural works is beyond the scope of this paper and the reader is referred to DLWC Riverwise Advisory Notes, DLWC (1993-8) and the authors for further information. Note that all the structures are designed to aid the establishment of riverine vegetation which then becomes the permanent self-repairing erosion control measure. Accordingly, for all the structures to be effective, livestock must be kept out of the stream and off the banks.

6.1 Bed raising options

In places where the bed has lowered, causing continued bank collapse from loss of support, the bed will have to be raised with bed raising structures which reduce stream power enough to cause bed deposition. This action may raise flood levels back to something approaching the 1974 levels, however further investigation is required to determine the extent of this effect. Annecdotal evidence suggests that at present all floods are contained within reaches.

The triple log sill structure is basically three logs anchored across the bed with only the top log exposed. This option is suitable where the bed is to be raised by less than 300 mm to raise a riffle and form a low flow pool. The banks at the site must also be protected to prevent outflanking. This option is suitable for the widened reaches where the bed has not lowered to any great extent. Note that if these are constructed on bedrock only one log may be required to raise the bed 300mm.

In the rock ramp structure (Figure 3), boulders are placed across and along the bed to form a long ramp. This option is suitable where the bed is to be raised for a significant distance upstream. A fishway slope of 1 vertical to 20 horizontal is necessary to satisfy the fish passage requirements of Fisheries. The canoe chute is to allow safe canoe and raft navigation, avoiding a portage around the structure.

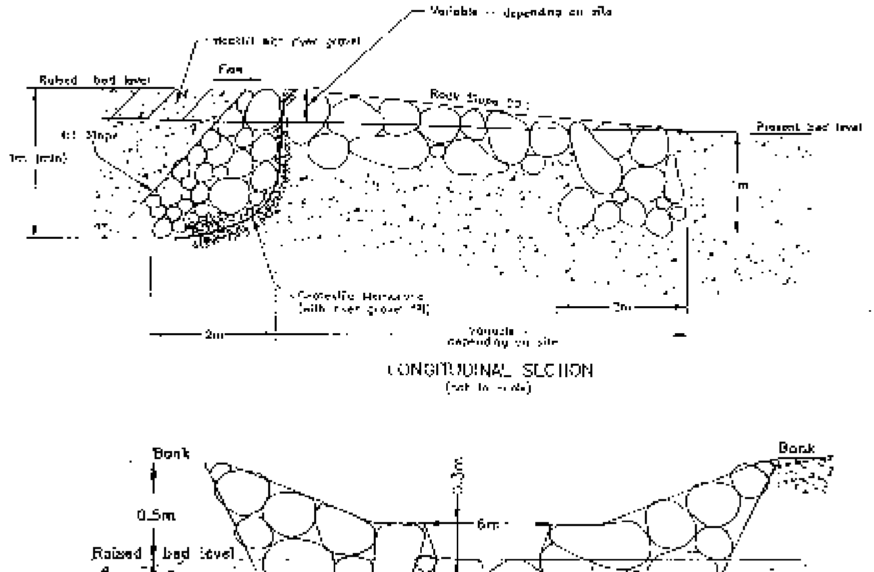

Figure 3: Example of a rock ramp with a fishway and a canoe chute.

Detail of the canoe chute part of the structure is being designed using the white-water rapids on Goolang creek as templates. This is better than modelling the structures in the laboratory as the Goolang creek rapids have the same design flow (power station maximum release: 860 ML/day) and they have been modified by the canoe club through trial and error to produce safe conditions. This also avoids the scale problems associated with laboratory models. However, a small stockpile of boulders should be left at each ramp site to allow minor modifications to the canoe chute and fishway after the first high flows which may cause minor boulder settling and movement.

An important construction requirement is that the boulders at the crest of the canoe chute and the fishway must be placed vertically and not dumped. This needs to be done so that they lock together and so that the fishway and canoe crests can have precise heights to get the proper distribution of flow. For ramps 1 metre high or less, the rest of the ramp can be made from dumped rock. For ramps over 1 metre high, all boulders must be placed vertically using an excavator grab. The curved crest and the low-centreline are also important features of the design.

The precise design of each ramp cannot be determined until the time of construction. The final structure will depend on the local foundation materials and on the size and shape of the boulders brought to the site. The median size required for the rock depends on the local depth of flow and slope.

Note that the heights of the recommended rock ramps are the minimum required to raise the bed upstream and reduce bank erosion rates back to natural rates. The occurrence of bank slumping and the rates of bank erosion must be monitored. If, after 5 years of normal flows (not drought years), the bed is not raised high enough and the accelerated bank erosion continues, then the rock ramps will have to be raised or further ramps constructed. To enable construction of these "contingency" rock ramps, where possible, construct the first ramps 80 metres downstream of bends. This will make it possible to construct contingency ramps (if needed) on appropriately straight sections of the creek. If the ramps are built too high at first, they may cause sediment "starvation" effects (degradation) downstream and accelerated deposition of extensive flow-deflecting bars and islands upstream.
The locations are chosen to reduce the stream energy between each structure and to drown out any nickpoints identified in the field. It is important that structures are located on straight sections of the creek and keyed into stable creek banks by 1.5-2 metres on both sides. The ramps must be constructed in the downstream reaches first to prevent nickpoints from moving upstream.

6.2 Bank erosion control options

In reaches where bedrock or gravel armour has prevented bed lowering, continued widening by bank erosion can be controlled by installing protection at the toe of banks on one side of straight reaches or on outside bends only. (The creeks are too narrow to allow the option of bend realignment). One bank will have to remain unprotected to allow minor width adjustment to continue. If both banks at a site are protected, the stream may start to break through its armour and the bed will start to lower. Both banks can only be protected where the bed is bedrock.

Rock revetment (rip rap) is the most reliable bank protection measure. It is a mixture of rock sizes with a large median diameter that is dumped at the toe of banks. However, it requires a nearby source of large run-of-quarry rock. The median size required for the rock depends on the local depth of flow and slope. The top of the rock should be one metre above the level of the maximum flow releases from the power station.

Another technique is a timber retaining wall built at the toe of eroding banks. This is less reliable than rock revetment but uses timber which is usually available on adjacent properties. The top of the wall should be one metre above the level of the maximum flow releases from the power station.

Snags can be anchored in all the pools along the creek. These are usually dead trees with their branches attached. This increases the channel roughness and increases the habitat for fish and macroinvertebrates. To avoid a navigation hazard, the snags should not protrude above the power station release water level. They should not be placed so as to deflect flow towards banks. They should be well anchored with cable and ground anchors.

7. RELATIONSHIPS BETWEEN WORKS AND STREAM BEHAVIOUR

The processes described in behaviour types 1 and 2 (section 3) will continue unless addressed through appropriate erosion mitigation works focussed on the creek bed. The objective of the works is to reduce erosion to a natural rate and to reinstate channel roughness, instream storage and aquatic habitat (ie. pools and riffles and woody debris).

Behaviour Types 3 and 4, respectively, describe reaches where the creek is recovering by itself and has already reached an equilibrium. Works are required in Type 3 style reaches where bars and islands have formed and are deflecting flows and eroding banks. The long term stability of the banks is ultimately dependent upon establishing native riparian vegetation.

Reaches described by behaviour Type 5 do not require any works.

Appropriate stock management in the riparian zone will assist channel recovery in all of the river behaviour Types. Stock exclusion will assist in stabilising the banks particularly in river reaches experiencing a Type 1 behaviour. The colonisation of gravel bars by vegetation assists in the recovery of channel form and narrowing of the channel. Narrowing of the channel will assist in creating deeper pools for instream storage and aquatic habitat. Therefore appropriate stock management is required to assist this recovery process.

8. SOCIAL CONSIDERATIONS

A review of environmental flow requirements has been a long term concern for landholders and environmentalists. Whilst land loss through streambank erosion has been an ongoing problem for landholders along Goolang and Blaxland Creeks, the recent environmental flow review is raising water access concerns. Access to power station discharge waters is an important economic and lifestyle consideration for landholders along Goolang and Blaxland Creek and the Orara River. Recreational canoeists and whitewater rafters also utilise the turbulent rapids and fast flowing discharge waters which characterise Goolang Creek. An environmental flow requirement for the Nymboida River is likely to impact upon these water users, particularly during low flow periods. Rehabilitation of Goolang and Blaxland Creek will alleviate these social impacts in part by:

- reinstating pools and therefore in-stream water storage;
- reducing loss of land through bed and bank erosion;
- reducing aggradation of the Orara River.

9. CONCLUSION

This investigation has revealed that the geomorphic response of streams to inter-basin transfer can be complex due to local variations in slope, bed/bank material, vegetation and human activities. One response is channel enlargement from bed erosion. This was not known when the previous large woody debris clearing and bank erosion control work was done. Accordingly, these works failed to control accelerated bank erosion rates.

Future rehabilitation works must be designed to utilise the local behaviour-determining factors to change the stream behaviour to restore equilibrium or at least reduce erosion rates to "natural" rates. The proposed rehabilitation works for these streams (such as log bed controls and bed-raising boulder ramps) have also been designed to enhance the riverine environment while providing for white-water canoeing on the power station releases.

10. REFERENCES

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