Tram or dam? A comparison of kauri logging transportation methods in the Kauaeranga Valley, New Zealand, 1871–1928

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Logging of kauri timber from the northern regions of New Zealand (NZ) in the nineteenth and early twentieth centuries played a major part in the development of the colony and, later, fledgling nation. Kauri timber also provided a very early source of export income. Mature kauri trees were of massive size and their growing locations in remote, rugged, bush-covered terrain meant that innovative transportation methods had to be adopted to harvest them. One such method was a system of driving dams, constructed within a river catchment, and tripped in a synchronized fashion when full (of logs and water). This study utilized GIS technology to develop a volumetric model of the driving dam system in the Kauaeranga Valley, which provides insights into how the system worked (particularly, its efficiency) and facilitated a comparison with other early systems of transporting logs (particularly tramways).

INTRODUCTION

Timber has always been a key material required for human existence:

> The cutting down of trees is universal, because wood, like water, is one of the necessities of everyday life. Every society in every age has used wood for fuel to keep warm, to prepare food and to provide shelter. (Williams 2003:xxii)

With the advent of the industrial revolution, however, the demand for timber was greatly enhanced: for building, transportation (particularly ship- and railway-building) and industrial processes and systems. European nations looked to distant lands to help satisfy demand for raw materials and this included sources of timber (Williams 2003:244).

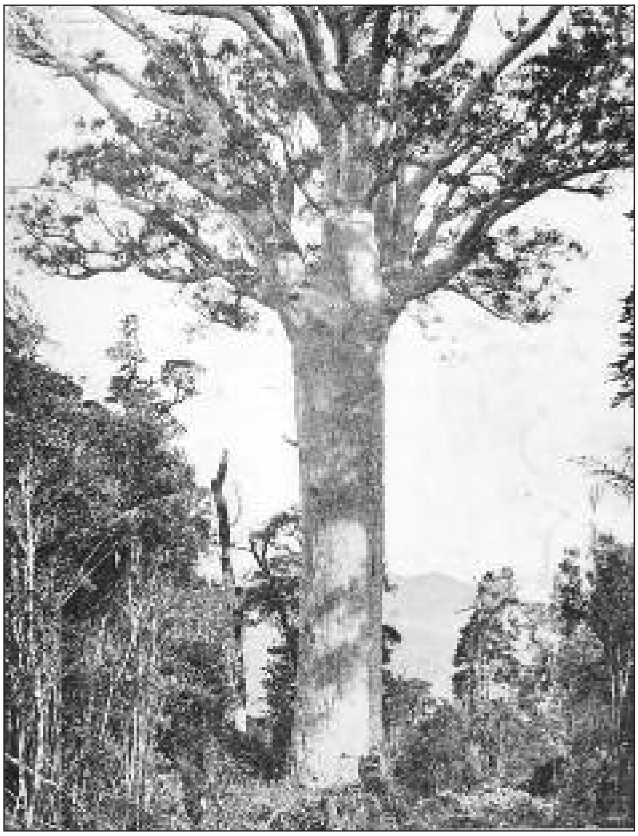

Figure 1: A timber worker dwarfed by a large kauri tree (DoC Kauaeranga collection).

When European explorers arrived in NZ in 1769 much of the northern part of the North Island was covered with kauri forest (*Agathis australis*). This provided a valuable source of timber for European nations and a source of early export income. Timber was later required for construction purposes in the fledgling colony but it also remained a source of export income well into the twentieth century. Kauri logging, however, was pursued so vigorously that only about 4000 hectares remains of the original 1.2 million hectares. Much forest was also lost to burning and clearing land for farming (Diamond and Hayward 1975).

Between 1840 and 1920 a substantial kauri timber industry developed in northern NZ. Many methods were used to move logs from felling sites in very rugged, bush-clad terrain to the timber mills, including bullock wagons, rolling roads, tramways and flotation of logs down natural waterways. The latter was probably the most common technique as it was cheap and the motive power of water was readily available (Reed 1953). This method was generally only able to be used for kauri as it is one of the few NZ native timbers that float naturally when first felled.

Driving dams were a key means of transporting logs from their felling-place in the bush down to timber mills. A dam was built across a stream and when it was full of logs and water it was ready to release. Dams were usually tripped in a synchronised fashion throughout a river catchment and usually in conjunction with a natural flood (or ‘fresh’ as it was known) to help drive the logs downstream. This resulted in spectacular drives of huge volume and power which brought thousands of logs at a time out of the bush.

The Kauaeranga Valley, east of Thames on the Coromandel Peninsula, was an important source of kauri timber. The Kauaeranga kauri industry operated for over 50 years, from the opening of the Thames goldfield in 1867 through to the late 1920s, when the supply of timber was effectively exhausted. During this time, over 1.5 million m^3 of kauri timber was removed from this one valley. An average kauri tree contained around 30 m^3 of usable timber, the largest up to about 500 m^3.

There were over 60 dams built in the Kauaeranga Valley (Hayward 1978). Initially dams were used to drive timber from the felling sites to sawmills in Thames or to the Firth of Thames, where they were collected into rafts and towed to sawmills in Auckland. In the 1910s pressure from farmers in the lower part of the Kauaeranga Valley resulted in a tramway being built, to avoid damage to the riverbanks, pasture and bridges caused by driving logs down the river. Dams were still used, however, in the upper part of the valley. By 1928 all of

Figure 2: A dam tripped, disgorging its contents of water and kauri logs (Matakohe Kauri Museum).

the accessible kauri within the valley had been logged and operations ceased. The tramway was pulled up and the dams, being temporary structures, gradually disappeared as bush slowly regenerated. The remains of some of these dams, however, can still be seen today (Diamond and Hayward 1975) and several have been recorded as archaeological sites.

The aim of this study has been to develop a volumetric model of the kauri driving dam system in the Kauaeranga Valley using a geographic information system (GIS), and then to compare the efficiency of the driving dam system with other transportation methods, particularly tramways. There has been previous research using GIS in relation to kauri driving dams. Napier and others (2007), for example, used GIS to provide quantitative data about dam placement in the Kauaeranga Valley and to test if the location of the dams matches descriptions from historical sources. This work did not focus, however, on the capacities of the dams in the valley and the overall efficiency of the driving dam system.

The present study was a multi-disciplinary research project. It incorporated elements of cultural heritage (particularly historical aspects), geography (particularly GIS) and information systems (specifically, modelling and simulation) to model a well-known historical phenomenon – the transportation of logs from the bush using a system of driving dams. The second phase of the study (comparison of transportation methods) utilised results from the volumetric analysis phase to compare the efficiency of the two methods, and historical and archaeological data to compare other aspects such as relative costs.

HISTORICAL BACKGROUND

Captain James Cook was the first European to note NZ's rich timber resources, during his first visit in 1769. NZ's timber industry dates back to the late 1700s, if one counts the first recorded felling of a kauri tree by a European. Several Royal Navy and commercial ships visited northern NZ during the late 1700s and early 1800s to cut and load kauri for masts and spars (Roche 1990). Large-scale timber milling, however, did not commence until around 1840 (Smith 2001).

Until the mid-1900s kauri was the most popular commercial timber in NZ because of its thick, straight trunk. The wood is soft but strong and long-lasting, and knot-free. Kauri was easy to work and rapidly became the preferred timber for boat-, house- and furniture-building. It was also a valuable export commodity and was used extensively in rebuilding San Francisco after the 1906 earthquake (Mahoney 2009).

The initial contract to log kauri in the Kauaeranga Valley was let to the Stone Brothers in 1871 (Hayward 1978; Isdale 1977). In that year the Stone Brothers built a massive boom just upstream from Thames and a large sawmill at Shortland, at the southern end of the town. Booms were structures designed to stop logs that had been driven down a river, allowing the water to pass through and resume its natural course. From 1888, however, a Melbourne-based syndicate, the Kauri Timber Company (KTC), became the dominant player in the kauri timber industry and bought the rights to numerous tracts of kauri forest and many sawmills (Pink 1988:9-10; Swarbrick 2009). This included logging rights in the Kauaeranga Valley and the Shortland Mill.

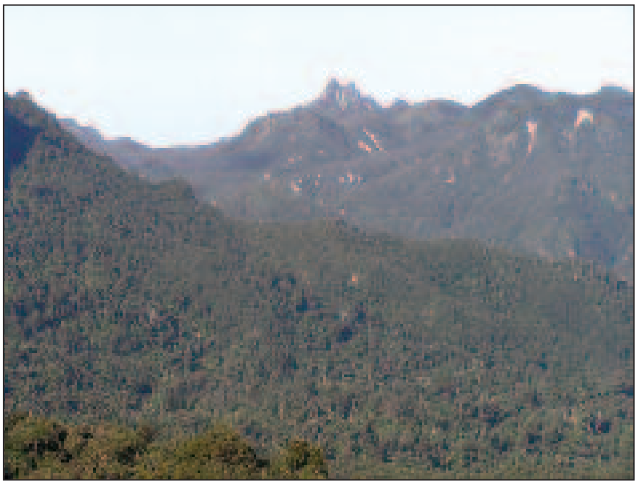

Figure 3: Typically rugged terrain of the Kauaeranga Valley. The area depicted was all logged for kauri (D. Wilton).

Getting logs from the bush to the mill could be a major challenge – the terrain was usually very rugged, and a big log might be 20 metres long and weigh 10 tonnes. The task became easier once the logs had been sawn at the mill as the volume of wood was reduced by over a third, and sawn timber could be stacked. Initially, the major sources of locomotion were human muscle, animal or gravity. Machinery, such as winches and tramways, later became prevalent.

Mahoney (2009) categorises the main methods of transporting logs as follows:

- Skidding: This is the simplest form, which is pulling the logs along the ground, using a winch or animal-power; or using gravitational forces (normally termed a log *chute*).
- Tracks (tramways): From the 1850s wooden tracks were used by loggers for rolling the logs on bogies (small carts) fitted with tram wheels. Iron rails were used later.
- Aerial: In early times, some logs were carried above-ground on ropeways. Helicopters were used in the twentieth century.
- Rivers: These were used to carry kauri, the one example of NZ native timber that floats when it is first felled. Dams were a common feature, used to drive logs on waterways that were normally too small to float large logs.

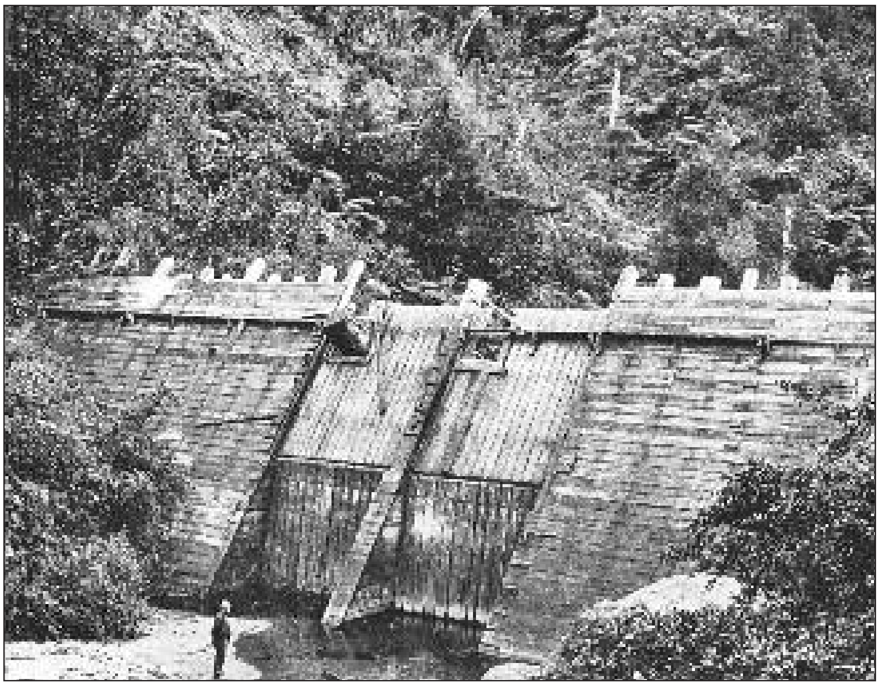

Figure 4: This large dam was on the Kapowai River, Coromandel Peninsula. The double gate was designed to let the water rush away quickly and give strength to the construction. The gates have been closed to allow the dam to refill. Over 8 million cubic metres of kauri were driven through this dam (Matakohe Kauri Museum).

- Roads: In the twentieth century roads were built and trucks were used to carry logs.

In the eighteenth and early nineteenth centuries, only two of these methods – flotation and tramways – were suitable for transporting large logs over long distances (i.e. in excess of about 1.5 km). The kauri logging industry of Northland and the Coromandel initially used water transport because it was considered to be the most economical. The driving dams and rafting techniques used were based on techniques first developed overseas (e.g. Canada) but were soon adapted to NZ conditions and became quite unlike those used in other parts of the world (Mahoney 2009; Offer 1997).

The technology of log-driving dams originated in Europe and was further developed in North America. Geographer Michael Williams (2003:259-260) notes that the first log drives were conducted in North America and involved felling trees and then moving them into stream and river beds, where they would be picked up and floated out during the spring thaw. Occasionally this process was assisted by the construction of 'splash dams', additional reservoirs designed to boost the spring floods. Logs were floated in this manner to larger rivers, where they were stored by booms, and often rafted together to be towed or gently floated out to the terminal destination, usually a sawmill.

In the 1850s the timber driving dams in west Auckland were copies of those in Nova Scotia, Canada. With no spring thaw, however, the system relied entirely on water stored in dams. The NZ dams evolved into a unique form including a simple but effective lifting gate design that allowed the dams to be released by a trigger and then re-used. Also, the dams built in NZ were adapted to drive logs via small streams, through very rugged terrain, which led to many design variations and innovations compared with the original North American designs:

Driving dams were a feat of engineering, built by talented craftsmen who learned by doing. Construction timber was felled locally and pit-sawn on site. Highly accurate hand sawing ensured the dam's facing planks were watertight. Considered judgement was required on the numbers, size and position of the heavy structural members that held the water behind. The master builders of dams and booms became legends, and their expertise was much sought-after. A measure of their skill is that only three dams are recorded as bursting. The re-usable gate also showed considerable local innovation. (Mahoney 2009)

Over many months a dam slowly filled, collecting a large amount of water on a fairly small stream. The logs were felled and directed into the dam or into the stream bed below it. The gate of the dam was tripped and the power of the water drove the logs down to navigable water. Dams were often tripped during a storm to enhance the natural flood. Within a single river catchment system, dams were usually tripped according to a time sequence, so that the quantity of water and logs accumulated as the drive proceeded down-river. Witnesses described the power of a large log drive, involving up to 40 dams, as unforgettable. A dam might be re-used for several years before it was abandoned.

After the logs were driven down the back-country streams they were collected in booms strung across the riverbed on the valley floor. Then the journey onward to the mill started. It often involved chaining the logs into rafts and towing them by steamer on a larger river or the open sea. The KTC rafted logs by sea to large sawmills at Auckland and at Mercury Bay in the Coromandel (Mahoney 2009).

Figure 5: Log drive at Goldies Bush in the Waitakere Ranges in the early 1920s (Matakohe Kauri Museum).

 

Figure 6: Dancing Camp dam (left) and Christmas Creek dam (right) undergoing partial restoration in 1998 (N. Ritchie).

In the early 1900s pressure from farmers in the lower part of the Kauaeranga Valley resulted in a tramway being built, to avoid damage caused by driving logs down the valley. Tramways were the other main method of transporting logs over long distances (apart from using waterways). According to Williams (2003), tramways evolved in Europe and predecessor versions relied on 'skidding' logs over snow or ice. Obviously this only worked during suitably cold weather and was soon replaced by use of sleds or skidded roads, where waste timber was laid perpendicular to the direction of travel, to prevent logs sinking into the mud. Eventually, these were replaced by main-line railways (where these ran close enough to logging operations) and then by temporary railway lines laid into the bush:

> … the construction of logging railroads as feeders took off in the Great Lakes states after about 1875. These logging 'roads' were lightweight, small-gauge lines that could be laid quickly to exploit the forest resource thoroughly, and then pulled up and relaid in another locality when the trees were cut out. (Williams 2003:263)

When all of the accessible kauri within the Kauaeranga Valley had been logged, the tramway was pulled up and logging operations ceased. The dams and bush camps gradually disappeared as the bush slowly grew back. In 1970 the remaining sections of native forest were protected as part of the Coromandel Forest Park. Today only two dams (Christmas Creek and Dancing Camp) remain reasonably intact. In the 1990s both of them were partially restored to ensure their survival. The remains of other dams can still be seen, however, and it has been possible to measure some of them.

CALCULATION OF DAM VOLUMES AND DERIVATION OF A VOLUMETRIC MODEL FOR THE KAUAERANGA DRIVING DAM SYSTEM

The first phase of the present study was intended to develop a volumetric model of the kauri driving dam system of the Kauaeranga Valley using a GIS. A 3D simulation of each dam site was built using ArcGIS and the dams' volumes were calculated by 3D analysis. An estimation of the total number of logs which could theoretically be floated by this volume of water was then made, which was compared with historical data of actual numbers of logs that were driven from the valley. This provided insight into the overall efficiency of the driving dam transportation method.

The study used ArcGIS and its 3D Analyst function to 'design' the dams (bearing in mind that they are now historical phenomena only) and to calculate their volumes. By using GIS data such as contour lines, this approach meant it was possible to create new surfaces as well as analyse surfaces. It was also possible to determine the surface area and the volume above or below a surface. The height was generally obtained from historical data, although the height of some remaining dams, e.g. Dancing Camp and Tarawaere, could be measured directly.

Topographic data used in the study were obtained from Land Information NZ (LINZ). The only available vertical data had 20-metre contour intervals. Since the dam heights of interest were less than 20 metres, the contour lines at the dam sites were estimated by comparing the 20-metre contour lines in the general vicinity of each dam and creating new contour lines with a lesser vertical interval by the Editor tool in ArcMap.

The next step was using 3D Analyst extension and creating a TIN (Triangular Irregular Node) from the dam's contour lines. At this stage, having the dam's TIN, surface analysis is available from the 3D analysis tool bar. Surface analysis calculates area and volume statistics for a surface above or below a reference plane at a specified height.

To verify the above method for calculation of dam volumes, two existing water supply dams, with capacities known from available engineering data, were chosen at random and their volumes calculated - Mangatangi dam in the Hunua Ranges and Upper Huia dam in the Waitakere Ranges. The difference in each case was less than 1%, indicating the validity of the method.

It was beyond the scope of the project to calculate the volumes of all 40 (+) dams used at any one time in the Kauaeranga Valley. In addition, historical data relating to height were unavailable for many of them. Instead the dams in the valley were divided into three categories, depending on whether they were on the main Kauaeranga River ('primary' dams – of which there was only one – the main Kauaeranga dam); on a tributary of the main Kauaeranga River ('secondary' dams); or on a tributary of a tributary ('tertiary' dams). An inventory of dams in use in the 1920s was compiled and the dams were classified into these three categories.

The volumetric modelling methodology described above was applied to one primary dam, three secondary dams and one tertiary dam. The results were then extrapolated to estimate the total volume of the Kauaeranga driving dam system. The results were as follows.

Dam volumes

- Primary: 130,000 m^3 – calculated volume of main Kauaeranga dam
- Secondary: 30,000 m^3 – weighted average of three secondary dam volumes (Dancing Camp, Tarawaere, Christmas Creek)
- Tertiary: 5000 m^3 – calculated volume of small dam (on tributary of Mangarehu stream)
- Total volume of Kauaeranga driving dam system = 130,000 + 15*30,000 + 26*5000 = 710,000 m^3

Hydrological analysis

- Source of climatic and hydrological data: Environment Waikato (n.d.)
- Average annual rainfall in catchment (measured at Pinnacles Hut) = 3.692 m
- Area of catchment = 122 km^2
- ∴ Total rainfall in catchment per annum = 3.692 x 122 x 10^6 = 450 million m^3
- Annual flow at river mouth = 1.9 x 10^8 m^3, indicating the remainder of the rainfall (2.6 x 10^8 m^3) is absorbed into the ground, vegetation etc.
- Water available in catchment to fill dams = 1.9 x 10^8 m^3 (42 per cent of total rainfall)
- % available water collected in dams = (7.1 x 10^5/ 1.9 x 10^8) x 100 = 0.4 per cent.

By contrast, the amount of water supplied by the Thames water race, which took water from the Kauaeranga River commencing in 1876, was 6 million gallons per diem (9.72 x 10^6 m^3 per annum) which represents 5.1 per cent of the available water from the river (Wilton 2009).

The result for the total volume of the kauri driving dam system obtained by GIS analysis is consistent with hydrological data for the Kauaeranga catchment. The total dam system volume represents about 1 per cent of the annual river flow (measured at the mouth).

The next step was calculating the total number of logs able to be floated by that volume of water. Knowing the density of newly-felled kauri (0.6g/cm^3), an estimated average log volume of 30 m^3, and using Archimedes' Principle of buoyancy and fluid displacement, the total number of logs able to be floated was calculated as 40,000. This means that if a solid object is less dense than a liquid, it will float in that liquid and the object will displace a weight of liquid equal to its own weight.

The largest-ever recorded drive in the Kauaeranga valley was 28,000 logs (Hayward 1978). Herman Lennon, a former bushman in the Kauaeranga, records a drive where he was responsible for tripping the main dam where '… the booms were filled up with over 22,000 logs' (Lennon 1972). Drives this large, however, were not common, with typical drives involving 2000–3,500 logs (Hayward 1978).

A drive of 28,000 logs represents an efficiency of 70 per cent in terms of the actual number of logs driven, compared with the theoretical maximum number that could be floated by that volume of water. This is surprisingly high, bearing in mind the vagaries of the terrain, the non-ideal shape of the logs (for the theoretical maximum number of logs to be floated, they would have to fit together with no gaps between them, which obviously is not the case), and the number of logs which got stuck in dams or were left stranded on the banks of streams or the main river. It is probably very much a 'best case' scenario and represents the outcome of very few drives when nearly everything went according to plan. Drives of 2000–3500 logs, however, represent a very low efficiency by normal industrial standards – in the order of 5–10 per cent.

COMPARISON OF TRANSPORTATION METHODS

Several means of transporting kauri (and other) logs were outlined earlier. However, only two of these methods were suitable for use on a large scale and over long distances, such as the Kauaeranga Valley logging operations of the late 1800s and early 1900s – driving dams and tramways. Other methods, such as steam haulers, aerial ropeways, skidded roads and animal power, were still used but at a local level: for example, getting felled logs into a dam or waterway, or to a railhead. Driving dams and tramways were both used in the Kauaeranga (including in combination during the 1920s), so this provides a good opportunity to compare these two key methods of transporting logs. This section provides a comparison, based on the following factors:

- operational effectiveness and flexibility,
- efficiency,
- cost, and
- legal and environmental factors.

Operational effectiveness and flexibility

Driving dams and tramways were both effective means for extracting logs from the bush, at least in the Kauaeranga area, but the most appropriate system depended significantly on the nature of the terrain. Dams had an inherent advantage in that the primary motive power (water) fell in a reasonably uniform manner throughout the catchment, so a dam could be built on nearly any stream that was close to a suitable supply of trees. Dams could thus be built where required and then abandoned after an area was logged out. However, tramway construction in the Kauaeranga area, particularly the Billygoat branch line with a maximum gradient of 1:2.3, showed that tramways could also be built in rugged terrain and probably provided an

Figure 7: Billygoat Incline (maximum gradient: 1:2.3) showing empty bogeys being winched up. Billygoat Falls can be seen near the centre (circled) (DoC Kauaeranga collection).

Figure 8: Upper Kauaeranga gorge. The KTC employed a team of miners from Thames to widen the passage sufficiently to allow log drives. The terrain was considered too difficult and too expensive to build a tramway through, or around, the gorge (DoC Kauaeranga collection).

equivalent amount of flexibility. In a few instances (e.g. the Billygoat), the terrain was actually too steep to drive logs from dams and work-arounds had to be devised; e.g. a tram line, or diverting logs and water into a stream with a lesser gradient.

There were also instances where it was not cost effective to build a tramway as the terrain was too difficult and the engineering challenges too great. With railway construction, global experience shows that nearly any engineering problem can be overcome with sufficient ingenuity and money. For example, some of the railways built in remote territories such as the Yukon and Alaskan gold rushes demonstrated very high levels of engineering innovation (Martin 1974). Logging tramways, however, were temporary structures, required for only as long as it took to harvest the trees in a particular area. An example of this situation was the steep gorge, towards the upper end of the Kauaeranga River. Rather than try to cut a tramway bed out of the steep, rocky walls, the KTC employed a group of gold miners from Thames to blast a passage wide enough for logs to be water-driven down the gorge without jamming. This took two years (Hayward 1978).

A major disadvantage of driving dam systems, in terms of flexibility of operations, was the reliance on the weather to provide suitable conditions for a drive. Dams had to be full and it was considered desirable to trip them in conjunction with a natural flood, or fresh, to obtain maximum efficiency. This often resulted in delays of a year or more and often led to inability to conduct sawmilling operations for significant periods of time, with consequent negative impacts on profitability and employment (Diamond and Hayward 1975; Hayward 1978).

Efficiency

As described previously, a 3D simulation of selected dam sites was built using ArcGIS and dam volumes were calculated using 3D analysis. An estimation of the total number of logs which could theoretically be floated by this volume of water was then made, which was compared with historical data of actual numbers of logs that were driven from the valley.

The largest-ever recorded drive in the Kauaeranga valley was 28,000 logs which represents an efficiency of 70 per cent. The overall efficiency of driving dam systems, however, was generally low – mostly of the order of 5–10 per cent. In transportation or industrial process terms, this would normally be regarded as very poor. The efficiency of tramways was much higher – barring occasional accidents, all logs that were loaded on to a tram were actually delivered to their destination, but in terms of costs this advantage was offset because the motive power of driving dams (water) was free.

The overall efficiency of driving dam systems was also degraded by factors such as logs getting stuck in dam gates or narrow gorges, or stranded on the banks of waterways. Considerable damage also occurred during (and even prior to) drives:

> Driving was very wasteful of timber, as much wood was lost through damage to the logs ... Much sapwood was also lost through deterioration during the time lapse between felling and milling. Most logs lay in a creek bed for three months to a year before floods filled the dams sufficiently for a drive. Between 1918 and 1928, 92 million [super] feet of kauri timber was felled and measured in the Kauaeranga Valley, but only 77 million [super] feet reached the booms or Kauaeranga tramline. The remainder was lost. (Hayward 1978)

Figure 9: A stump jammed in the gate of a dam after a drive. This caused a back-up of most of the other logs in the dam (DoC Kauaeranga Collection).

Figure 10: Logs left stranded on the banks of the Kauaeranga River after a drive. Gangs of men, known as 'trimmers', were employed to jack or winch logs back into the main stream bed (DoC Kauaeranga Collection).

Driving dam systems were also subject to vagaries of the weather, as noted previously. In terms of overall efficiency, tramways offered clear advantages over driving dams.

Cost

Offer (1997) notes that tramways were generally regarded as a more expensive means of extracting kauri logs from the bush than the use of water power through dams and booms:

> Tramway development was extensive in the Waitakeres [Ranges] and elsewhere, and was expensive to construct. Concerning Canadian experience ... Kennedy in 1931 says: "I believe that, where possible, logs should be driven rather than hauled. Using costs of hauling over similar distances and similar territory as a basis of comparison, expensive drives are cheaper than the best organized hauling operations which might have replaced them." (Offer 1997)

Cost analysis includes two distinct elements: capital (i.e. initial cost of construction) and ongoing operating costs. In terms of the costs of the Kauaeranga systems, the following is a brief comparison.

Capital costs

The recorded cost of construction of the Kauaeranga tramway system was £40,000 (Hayward 1978). Although it is not clear whether this is just for the main line or included the branch lines, it can be regarded as a minimum figure.

Campbell-Walker, the NZ Conservator of Forests (1877), appeared to favour tramways:

> The universal use of the tramway forms a marked feature in the treatment of New Zealand forests. I have seen them of all descriptions, and no saw-miller ever dreams of working a forest without one. They are, as a rule, constructed by bush-men on contract, the price per chain varying greatly, according to locality, nature of the country in which the forest is situated, and size of timber to be taken out ... Floating is common for the transport of timber in the Auckland district, where dams are constructed on the smaller rivers or streams to store up the water till required. One of those which I saw at Mangawhau cost as much as £1,000.

Campbell-Walker also reported the cost of laying one particular tramway:

> From Kaihu [north of Auckland] we visited the Whakara Forest further up and on the left bank of the [Northern Wairoa] river. The kauri here was very fine, and we observed one tree of ten feet diameter. There is a fine tramway for bringing out the timber to the river, which is stated to have cost £5 per chain, or £400 per running mile. The laden trollies are drawn by three horses.

This would appear to be very much a 'best-case' figure, in level, open country, as the author states that bogey trains of logs were pulled by a team of three horses. Or it may be significantly understated. Evidence given to a House of Representatives Select Committee in 1873 included projected tramway construction costs of £2000 per mile in 'land fit for a tramway' and £7000 per mile in 'rough' country (Select Committee 1873).

By means of comparison, the cost of building 7.5 miles of tramways for the Thames goldfields was £31,000, an average cost of about £4100 per mile (Bullock 1964). These lines were built from stream valleys in the hills surrounding Thames to the coastal plain on which the town is situated, and the terrain is comparable to the Kauaeranga Valley. This average cost is roughly mid-way between the two figures presented to the Select Committee and supports their validity.

An analysis of the indicative capital costs of construction of the Kauaeranga tramway system using the figures presented to the Select Committee is provided in Table 1, using terrain data gathered during the archaeological site survey and records (Wilton 2008).

The estimated total capital cost of the Kauaeranga tramway system (track-laying only) is within about 10 per cent of the historical figure (£40,000) recorded by Hayward. According to Diamond and Hayward (1975), 'Depending on its size, it took a team of bushmen from one to twelve months to build a dam while the cost in those days could vary between £100 to £1000 or more.'

Table 1: Indicative capital costs of Kauaeranga tramway system

Line segment	Total length (km/miles)	'Fit' country length/cost at £2000 per mile	'Rough' country length/cost at £7000 per mile	Line segment cost
Main Kauaeranga line (Atuatumoe Stream junction to Firth of Thames)	18.5 km			
	11.5 miles	10 miles	1.5 miles	
		£20,000	£10,500	£30,500
Billygoat branch line	2.4 km			
	1.5 miles	0.7 miles	0.8 miles	
		£1400	£5600	£7000
Hihi branch line	1.7 km			
	1.0 miles	0.8 miles	0.2 miles	
		£1600	£1400	£3000
Piraunui branch line	0.3 km			
	0.2 miles	0.2 miles	–	
		£400		£400
Mangakirikiri branch line	2.0 km			
	1.2 miles	1.0 miles	0.2 miles	
		£2000	£1400	£3400
Totals:	**15.4 miles**			**£44,300**

These figures are consistent with those provided by Reed (1953): 'The sub-contractor's price for building a dam might vary from a hundred pounds for a very small one to six or seven hundred pounds, or even a thousand pounds for a large one.

The figures are also supported by an article in the Auckland *Daily Southern Cross* newspaper of 13 January 1888 which stated:

> During the last fortnight there has been a bush fire raging at Cabbage Bay [now called Colville] which has destroyed Cadman's new dam, also 50 kauri logs. The dam had only recently been erected at a cost of £600.

Using estimated construction costs of £1000 for a large dam, £600 for a medium, and £200 for a small, and the classification of Kauaeranga dams in a preceding section, the total construction cost of 42 dams would have been 1000 + 15*600 + 26*200 = £15,200. Adding £3000 for the cost of a set of main booms (based on the cost of the Parawai booms in 1871 [Isdale 1977]), the total capital cost would have been of the order of £18,200 – less than half the cost of the tramway system.

Operating costs

The Kauaeranga tramway operators (brothers Bill and Les Nankivell) were paid one shilling and two pence per 100 super-feet to transport logs to the tramway terminus, out of a total cost of seven shillings and sixpence per 100 super-feet to land logs in Auckland (Hayward 1978). This represents approximately 15 per cent of the total operating costs and is a significant portion of the cost of production.

The operating costs for the driving dam system are not directly recorded, but would almost certainly have been much less as the main motive power (water) was free and no machinery was required. Operating costs for a dam system, however, would not have been inconsequential: staff were required for tripping dams (as this was done sequentially, all dams involved in a drive would have been manned simultaneously) and resetting them after use. Dams needed to be repaired and maintained to retain their waterproofing, and gangs of trimmers were employed to re-float stranded logs. However, all these activities would have only been needed on an occasional basis, i.e. before and after a drive; unlike operation of the tramway system, which was a daily task.

Based on the analysis above, the cost of constructing the driving dam system in the Kauaeranga Valley was less than half that of the tramway system and the operating costs would have been significantly less. This supports Offer's (1997) contention that: 'expensive drives are cheaper than the best organized hauling operations'.

Legal and environmental factors

The principal legal basis for driving logs on NZ waterways was the *Timber Floating Act* of 1873, which was revised in 1884, 1893, 1909 and 1954. It remained on the statute books until 1986 when it was repealed by the *State-Owned Enterprises Act* (Offer 1997). Unlike the Conservator of Forests, the Select Committee into the Timber Floating Act appeared to favour dams over tramways (Select Committee 1873). Their report stated:

> The Committee are of opinion that the power possessed by lower holders on the banks of a creek, to obtain an injunction to prevent the floatage of timber by upper holders, is liable to be abused, to the injury of a most important industry.

However, there appeared to be a degree of compromise, or possibly political pragmatism, in the qualifying statements:

> At the same time the Committee are of opinion that it would not be advisable in some creeks, adjacent to which settlement is progressing, to permit the driving of timber except under stringent regulations ... and that licensees should give security adequate to meet the claims of any persons whose property they may damage.

As settlement progressed and land was cleared for farming and other activities, conflicts of interest soon began to occur. According to Hayward (1978), logs were driven down the Kauaeranga River to the Parawai booms until about 1908. By then, farming was well established in the lower valley and farmers were understandably irate about their land and facilities being damaged by log drives. The *Thames Star* editions of 17 and 18 August 1898 recorded legal action brought against the Kauri Timber Company:

> The case of Dodd v. the Kauri Timber Company, which was commenced on Monday, before Mr Bush, S.M., and Messrs Tizard and Swindley, assessors, was continued this morning. Robert Nesbitt Smith stated he had never seen a higher flood than that of June 23rd, during the last 20 years. He noticed the river fall suddenly on one occasion. This was due to the fact that there was a breach in the booms. His own property had been damaged by logs, and had been damaged by the recent flood. He had taken action against the Shortland Sawmill Company some years ago. On that occasion, the damage was caused partially by the backing up of the water ... He succeeded in his [earlier] action against the Sawmill Company.

We have been unable to determine the outcome of the case. From about 1908, however, the KTC commenced development of the Kauaeranga tramway system, which was in use by about 1920, following a hiatus in work during World War I. The KTC could probably have continued to legally drive logs down the Kauaeranga River in terms of its licence under the *Timber Floating Act*, but the effects on the settlers in the lower valley had become significant and the costs of compensation were mounting.

The use of dams and booms to get logs out of the bush relied on a combination of full dams and natural flood conditions on the river. The severity of these was hard to predict and there were several incidents when the Parawai Booms broke under the force of water and logs, and logs went out to sea. Local boatmen were paid on a per-log basis to retrieve them and bring them back to the wharf. According to the *Daily Southern Cross* of 18 November 1873:

> A flood in the Kauaeranga River today brought down 800 logs from the Shortland Saw Mill Company's bush. They came down with tremendous force, smashing and carrying away the booms, breaking 1 3/4 in. chain, and some of the logs floated out to sea. A large number were recovered near the mouth of the river, but a lot were soon lost sight of. Boats are out in all directions to secure as many as possible, and the steam launch will be sent out in the morning. The manager expects to recover the greater number of them.

There were also reports of runaway logs damaging boats on the Firth of Thames in 1882 (Hayward 1978). The *Thames Star* of 19 June 1884 reported:

> The wet weather we have had since Tuesday night last culminated in a steady downpour last evening, which caused all the creeks and the Kauaeranga river to become much swollen, and considerable damage was done, chiefly in the Borough, while the logs which came down the river when the booms broke, made a hole in the p.s. Patiki, lying at Shortland Wharf.

Figure 11: 'Before' and 'after' scenes of a bush creek subjected to a log drive (F.J. Causley collection, Coromandel Heritage Trust, Thames).

The original bridge over the Kauaeranga River, providing road access to Thames, was built in 1877. Continual battering by logs weakened it so that:

> February 1917 saw Thames take stock after bad flooding … The bridge over the Kauaeranga … was swept away … Battering by kauri logs was a key factor, and the Thames County Council wanted the Kauri Timber Company to reconstruct the bridge. (Isdale 1977)

It is not recorded whether the KTC complied or not. However, the bridge *was* rebuilt, only to be swept away for a final time in May 1925 (Isdale 1977). It was rebuilt shortly afterwards, at a different site, further downstream.

Driving dam systems also had a significant effect on the ecology of the waterways that logs and water flowed down (Napier *et al*. 2007). These effects are still apparent some 80 years after their use was discontinued. The main effect was the scouring of waterways down to bedrock which destroyed the flora and fauna, including aquatic insect life and fish.

Tramways were also subject to legal controls and required a licence and safety inspections to operate. They were less obtrusive, however, in terms of environmental impacts and damage. The atmospheric pollution associated with coal- or wood-fired engines would be of concern today, but obviously was not, in the nineteenth and early twentieth centuries.

SUMMARY AND CONCLUSIONS

In this study a volumetric model of a kauri driving dam system has been developed using ArcGIS and the efficiency of such a system compared with other transportation methods, primarily tramways. A set of driving dams within a river catchment can be considered to be a *system* because the dams were tripped in sequence to build up a 'wall' of water, to maximise the ability to convey logs.

The amount of water available to fill dams and the maximum number of logs which could be floated was calculated. The efficiency of kauri driving dams system was estimated as 70 per cent for the largest-ever recorded drive and around 5–10 per cent for typical drives. Even though the efficiency of the driving dam system was quite low, its low operating costs, compared with tramways, made it the preferred method of moving logs at that time. According to Offer (1997):

> Tramway development was … expensive to construct … Using costs of hauling over similar distances and similar territory as a basis of comparison, expensive drives are cheaper than the best organized hauling operations which might have replaced them.

Kauaeranga Valley kauri logging operations provide a good case study that allows the relative merits and pitfalls of driving dams systems and tramways to be explored. The main advantages of driving dam systems, relative to tramways, were low capital and operating costs, especially in terms of the ubiquity and zero cost of the motive power; i.e. water. However, there were downsides to this – driving dam systems were subject to the vagaries of the weather (in particular, drought conditions), and the overall efficiency was significantly degraded by factors such as logs getting stuck in dam gates or narrow gorges, or stranded on the banks of waterways. Considerable damage also occurred during (and even prior to) drives. Driving dam systems can also be considered inferior to tramways with regard to environmental aspects, such as damage to eco-systems and human structures.

The above statement by Offer (1997) with regard to the lower cost of driving dam systems is supported, but other factors tend to support the tramways option. As with any business venture, a sound business case which takes into account actual conditions needed to be developed to determine which (if any) was the best option; to ensure profitability and an acceptable level of risk.

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