Lies, dam lies, and statistics: the compilation and analysis of a New Zealand Inventory of Dams

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Dam inventories can provide a comprehensive understanding of a region's dam population; from dam quantity, type, age, height, and purpose; to ownership profiling and broad-based regional risk assessment using GIS applications. Historically, New Zealand has lacked a comprehensive inventory of dam assets, instead relying on local and industry knowledge to characterise the dam infrastructure and its key properties, issues, and risks.

This paper presents a cross-sectional characterisation of dams in New Zealand, based on the recent compilation and analysis of a New Zealand Inventory of Dams (NZID). The NZID is the first inventory of its kind for NZ dams, comprising almost 1200 unique structures over 3 m in height. Inventory data was sourced from existing publications, NZSOLD, and regional authorities. The analysis of anonymised inventory data provides an understanding of the number and distribution of assets, along with characteristic physical properties (construction material, height, age, purpose).

Statistical comparisons are drawn in relation to published international dam inventories. Similarities and differences in the international dam populations are noted, particularly with regard to construction era and type. The NZ portfolio is unique in that dams are typically shorter in height, and a significant proportion of structures serve the hydroelectric and energy sectors.

Analysis of the new NZID confirms the need for research that is focused on the long-term performance of aging earth dams, particularly those exceeding 40 years of age. In addition to informing research needs and foci, the new NZID provides statistics on the dam population with far-reaching industry and management applications.

Keywords: *dams, inventory, characterisation.*

Introduction and background

The University of Canterbury Quake Centre Earth Structures (Dams) Project

Water-retaining dams form a vital part of New Zealand's critical infrastructure, providing electricity, potable water and irrigation resources to a large proportion of the country. The damage or failure of these structures would incur a significant potential financial loss to the country; not only from the physical repair or rebuild cost, but also the potential for extended outages in power generation and/or municipal water services. In addition, dam deterioration accompanied by uncontrolled release of water represents a significant risk to safety for downstream communities.

Internationally, a number of long-term research programmes have been established to address industry concerns regarding the ongoing performance of aging dam infrastructure (e.g. Garner and Fannin, 2010). On a local scale, the challenges faced in the management of aging embankment dams are compounded by factors specific to New Zealand, including large variability in soil types and the highly tectonic environment in which the dams are located. A better understanding of the soils from which dams are constructed is necessary to ensure long-term performance and effectively manage risk.

Since 2010, significant engineering resources have been mobilised within NZ as a result of the Canterbury Earthquake Sequence (CES). While no large earth dams appear to have been significantly or directly impacted by the CES to date, the wider engineering impacts on infrastructure arising from the CES have highlighted the need for improved engineering guidance for dam owners.

The University of Canterbury Quake Centre (UCQC) was established in 2013, creating an environment in which professionals and academics can collaboratively explore viable earthquake engineering solutions. The UCQC Earth Structures (Dams) Project was initiated in response to local industry demand for improvements in the state of geotechnical dam engineering, with a particular focus on providing rational, mechanism-based guidance for evaluation of the performance of embankment dams during strong earthquakes.

Objectives of New Zealand Dam Characterisation Project (New Zealand Inventory of Dams)

The UCQC Earth Structures (Dams) Project was initially proposed by large hydropower asset owners in New Zealand to address uncertainties regarding the long-term performance of embankment dams in seismic environments. Discussions with industry stakeholders identified a number of commonly-held beliefs regarding the composition of New Zealand's dam assets. Common assumptions include:

- Most dams in New Zealand are earth dams.
- Most large dams are owned/managed by large companies and, therefore, the application (or awareness) of New Zealand Society on Large Dams (NZSOLD) guidelines is implied.
- A large proportion of dams were built in the 1940s to1960s.
- The era of large dam construction is over due to the present social and regulatory environment.

While these assumptions are likely justified, they remain largely unquantified in the New Zealand context. Acknowledging that hydropower assets comprise a significant, but not total, proportion of the country's largest dams, the project team sought to define an objective basis for selecting and refining the properties of most importance to future dams research. Specifically, an understanding of the NZ dam asset portfolio was necessary to verify the research proposition and direction. As a result, the UCQC Earth Dam Characterisation Project was born.

The main objective of the characterisation project is to determine representative properties of the New Zealand dam portfolio, in order to refine research parameters at the outset of the long-term UCQC Earth Structures (Dams) Project. Specific goals of the characterisation project include:

- Determine the number of earth dams in New Zealand (and proportion of earth dams in terms of total asset count).
- Gain an understanding of typical or characteristic dam height (governing seismic attenuation/amplification factors).
- Gain an understanding of asset properties across the portfolio (e.g. height; purpose; type; geographical and geological distribution; age), with particular reference to engineering design and construction practices at the time of construction.
- Determine the typical properties of High/Medium Potential Impact Category (PIC) dams.
- Use spatial location data to determine characteristic fault proximities and regional geologies.

These objectives could be met only by way of analysis of an up-to-date and comprehensive list of dam assets in New Zealand. At the outset of the UCQC Earth Structures Project the available lists of dams proved highly variable in their quality and attributes, and were largely out-of-date, incomplete, or limited in their nature. Hence, a standardised NZ Inventory of Dams (NZID) was required to move forward.

Beyond research applications, the dam characterisation study has important implications for the risk management and regulatory fields. The NZID will serve to inform owners, engineers, technical interest groups (such as NZSOLD) and regional/unitary authorities as to asset distribution, portfolio characteristics, and risk profiles.

Scope of this paper

While the detailed analysis phase of the UCQC Earth Dam Characterisation Project is ongoing, the draft NZID is complete. This paper provides a fundamental overview of the dam asset portfolio in New Zealand, in terms of basic properties characterised within the draft NZID (Version 1.1). This paper focuses on population data and spatial analyses are not considered.

Methodology

The dam characterisation project initially sought to collate and verify existing dam datasets, and incorporate additional information provided by dam owners, consultants, and regulatory authorities. The intent is to provide a single, reliable, and spatially-referenced inventory in the form of the NZID.

The development of the NZID involved the following steps:

- Compilation of existing dams lists, including:
    - NZSOLD (1989). Dams in New Zealand. New Zealand Society on Large Dams.
    - Ministry of Commerce (1988). New Zealand Dam Inventory.
    - Consultants' portfolios.
    - Owners' portfolios.
    - NZSOLD list of Large Dams (provided to ICOLD for the World Register of Dams).
    - Recent information provided by regional and unitary authorities.
- Combining and merging of lists;
- Extensive quality assurance including;
    - Verification and correction of entries and attributes, through:

- Identification of attribute conflicts, errors, or mismatches,
  - Identification of duplicate records,
  - Completion of missing information using resource consent data, aerial photographs, Google Earth Historical Imagery, and other sources.
- Preliminary synthesis by way of Excel PivotTable.

The NZID includes all available structures over 3 m in height while recognising that, in practice, many of the contributing lists have focused on larger (implied higher-risk) structures. Accordingly, the NZID V1.1 is viewed as an evolving dataset. Despite extensive verification, is expected that entry and attribute errors will persist. Future versions of the NZID will benefit from additional corrections and additions arising from Geospatial Information System (GIS) analysis. However, for the purposes of cross-sectional analyses presented in this paper, the V1.1 inventory is considered sufficiently accurate to provide an understanding of fundamental properties across NZ's dam portfolio.

The New Zealand Inventory of Dams: Dataset properties and limitations

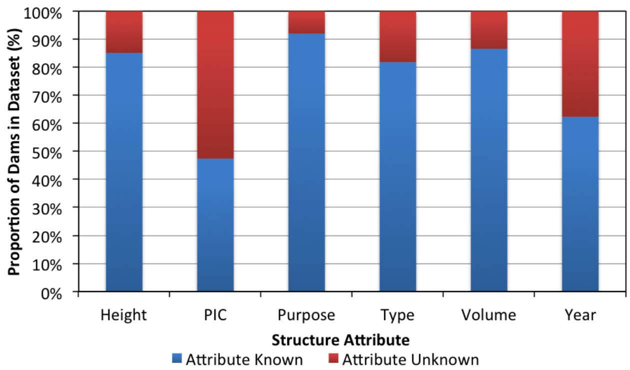
Dataset attributes, properties and completeness

The NZID V1.1 comprises 1194 structures greater than 3 m in height (or of unknown height, assumed to be >3 m). Contributing data lists were last updated in late-2015. The attributes considered for the purposes of the fundamental characterisation are as follows:

- Year: Year of construction or commissioning
- Type: Dam type (material)
- Height: Maximum height of dam, above foundation (m)
- Purpose: Dam purpose/s
- Potential Impact Classification (PIC)
- Volume: Reservoir volume (10^3 m^3)

Additional attributes included in the NZID include (where applicable; some properties restricted):

- Dam name
- Identifier (resource consent, regional authority, or other)
- Owner
- Location (region, regulatory authority, spatial coordinates)



Attribute	Attribute Known, % (value)	Attribute Unknown, % (value)
Height	85% (1016)	15% (178)
PIC	47% (566)	53% (628)
Purpose	92% (1098)	8% (96)
Type	82% (977)	18% (217)
Year	62% (744)	38% (450)
Volume	87% (1034)	13% (160)

Figure 1: NZID V1.1 Completeness of attribute data (1194 structures)

The NZID dataset proves largely complete for most readily-inspected dam attributes, such as purpose (provided for 92% of structures), type (82%), and height (85%). Reservoir volume is also reported for a high proportion of entries (87%); interestingly, more so than dam height (Figure 1). The relative absence of PIC data (unknown for 53% of structures) is perhaps to be expected. Unlike other dam attributes, the determination of PIC requires specific engineering input. Similarly, the age of a dam (year of completion/commissioning unknown for 37% of entries) can be difficult to determine, particularly in the case of smaller structures where ownership may have changed multiple times throughout the life of the structure.

Unknowns, uncertainties, and limitations of present analysis

As noted above, the NZID V1.1 is viewed as a largely complete, yet evolving, dataset. Further work will seek to include additional structures, define unknown attributes and improve data accuracy.

While all available structures greater than 3 m in height are presently included in the NZID, it is expected that many small NZ dams will be missing from the inventory. At a practical level, it must be emphasised that the delineation of smaller earthfill structures in the context of surrounding topography is not an easy task, particularly where earth structures have existed as part of the 'natural' landscape for decades. Assuming a high level of accuracy in the coverage of larger structures, future statistical studies could model the likely frequency distribution of smaller structures.

Some error is to be expected in terms of inconsistent attribute reporting. Depending on the data source, dam attributes may be reported by the individual owner, engineer, regulator, or other person. For example, while the "Water Supply" category is intended to cover municipal and industrial water supply, it is possible that dams built for treatment, stock water, or irrigation have been categorised as water supply dams. Similarly, dam volume may be reported at maximum operating level, maximum flood level, or at crest level. While extensive data quality checks have been made (as described above), minor attribute errors may persist.

Overall, it is likely that Potential Impact Category (PIC) data, where available, is un-conservative. While PIC attributes have been verified for dams in the NZID where possible, many PIC values date from the late 1990s or early 2000s. Given increasing levels of rural and urban land development, many PIC classifications will have changed significantly in the last five to 20 years. Specifically, the present re-assessment of structures deemed Low PIC could result in a higher PIC classification due to surrounding land use changes in recent years.

In general, the analyses presented in this paper are intended to illustrate fundamental properties of the national NZ dam portfolio. While findings are inherently limited by the completeness and accuracy of the source data in the NZID, the source dataset is considered largely accurate and representative, and unknown properties are identified throughout the analyses presented herein.

The NZ dam asset portfolio: fundamental properties and trends

Dams in New Zealand

Dam types

The large majority (74%) of dams in the NZID V1.1 inventory are classified as Earth dams (inset, Figure 2). It is expected that a significant proportion of dams of unknown type (18%) are also of earthfill composition. Concrete structures of all types (arch, buttress, gravity, and composite) collectively comprise 6% of structures. Composite (mixed type) structures and rockfill structures each account for approximately 1% of structures in the inventory.

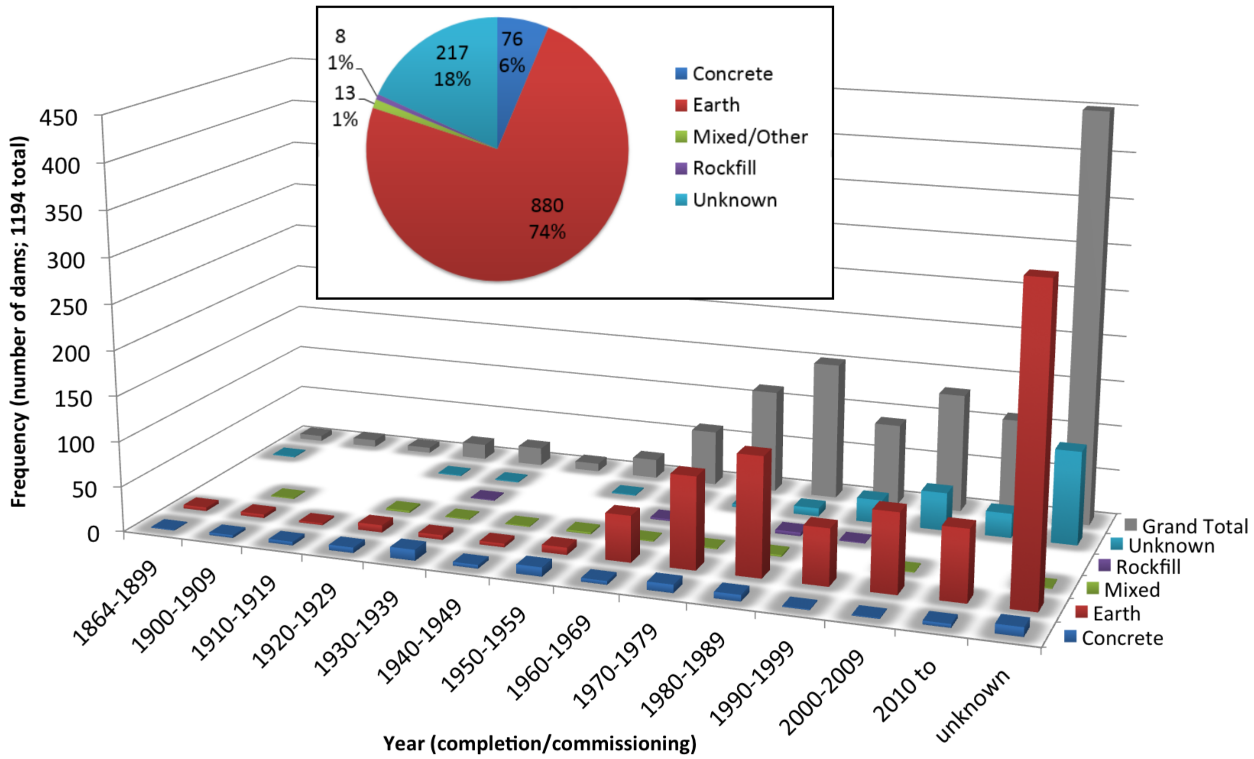


Figure 2: NZID V1.1, All structures by Type and Age

The distribution of structure type with year of completion (or commissioning) is presented in Figure 2. The total number of structures (all types) for each construction period is also shown. Disregarding structures of unknown age, the peak decade for dam construction in New Zealand appears to have occurred in the 1980s, following a steady increase in new dams built each decade from the 1950s. The number of new dams commissioned almost halved between the 1980s and 1990s, with some recovery in numbers since.

Since 1960, earth dams have accounted for the majority of new dams built, while most concrete structures were built between 1920 and 1989. Few concrete structures appear to have been commissioned later than 1990 (Figure 2).

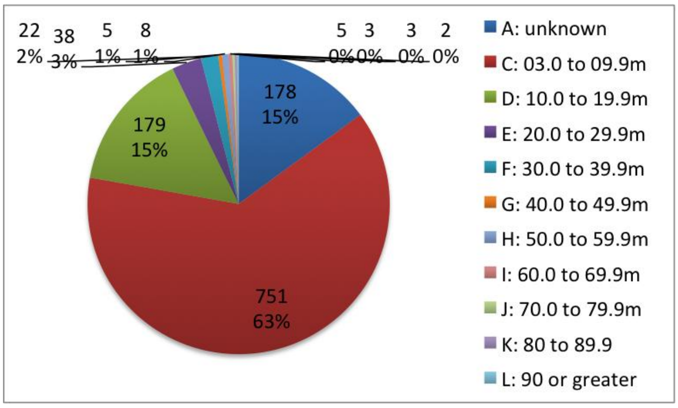


Figure 3: NZID V1.1, All structures by height (m)

The overall composition of the NZID is provided in terms of dam height in Figure 3. Dams of unknown height account for 15% of inventory entries. The majority of structures (63%) are less than 10 m in height; with an additional 15% of structures between 10 and 20 m in height. Seven percent of dams exceed 20 m in height, while 1% (13 structures) exceed 60 m.

In the interests of brevity, a full breakdown of dam height is not provided in relation to dam type or completion year. Earth and concrete dams are equally represented in the tallest 1% of structures (>60 m in height) and most of these structures (11 of 13) were constructed prior to 1989.

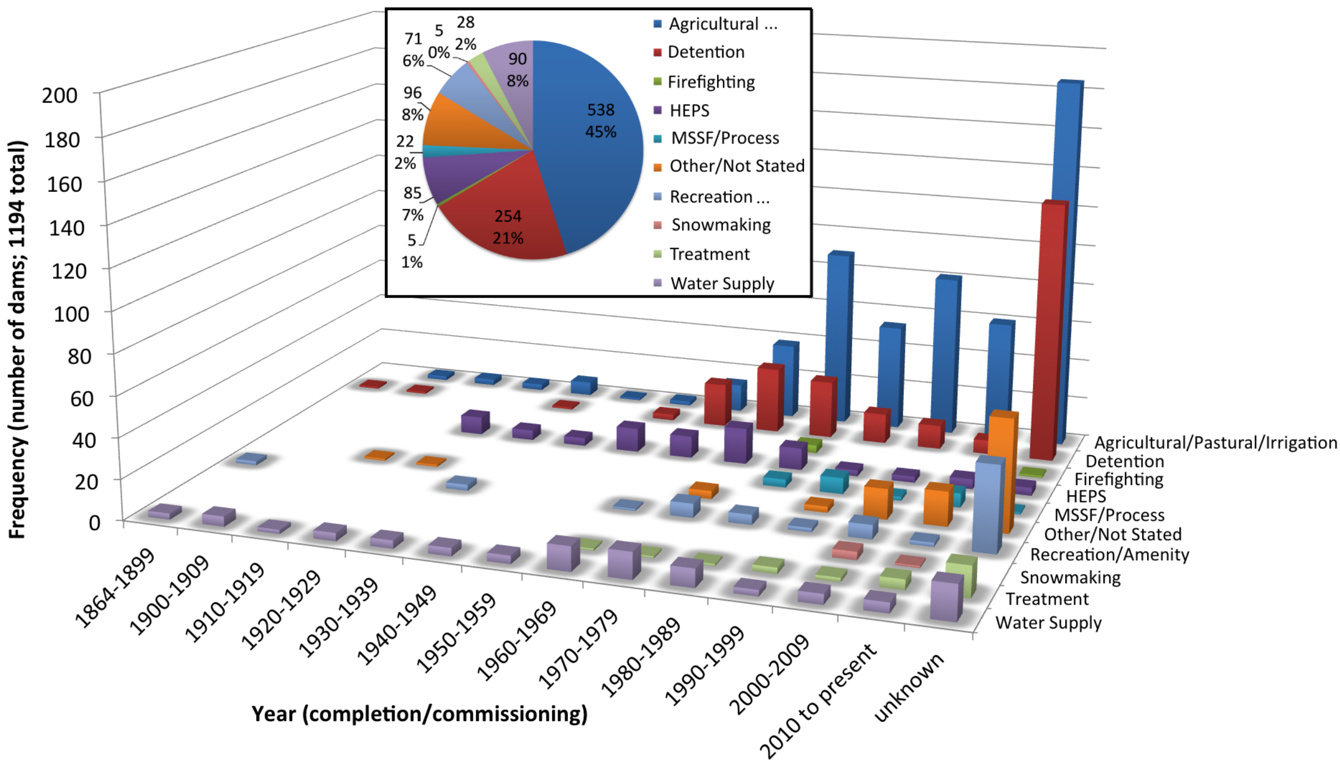


Figure 4: NZID V1.1, All structures by primary purpose and age

The distribution of primary dam purpose with year of completion (or commissioning) is presented in Figure 4. Dams used for agricultural, pastural, or irrigation purposes account for 45% of all NZID structures. Since 1980, the vast majority of dams constructed in New Zealand have been built to service the agricultural/pastural/irrigation sector, including 65% of dams built from 2010-2015.

Stormwater and flood detention needs have resulted in a significant detention dam asset base (21% of all NZID V1.1 structures); however, around half of detention dams (51%) are reported to be of "unknown" age. Based on known attributes, most detention dams appear to have been constructed between 1960 and 1989. The demand for detention dams appears to have reduced in recent decades; however, detention dams have continued to feature notably in newer dams built from 2010 to 2015.

The 1920s saw the development of dams to support NZ's growing Hydro-Electric Power Schemes (HEPSs). HEPS structures contributed significantly to the total number of dam builds from 1920 through to 1989, with most HEPS structures commissioned between 1950 and 1989.

Water Supply dams have formed a vital part of dam asset base since the 19th century, with a relatively consistent number of dams built each decade for water supply purposes. The peak period for construction of water supply dams appears to have occurred during the 1960s and 1970s. Of all purposes, water supply structures feature most consistently across NZ's dam construction history.

In recent decades, dams have been constructed for more 'modern' purposes, including Mineral Solid Storage Facilities (MSSF, including process/tailings waste; 1980 to present) and snowmaking (2000 to present).

High and Medium PIC structures

As previously outlined, Potential Impact Classification (PIC) information is detailed for just under half (47%) of all structures in the inventory. NZSOLD guidelines define PIC in terms of three impact levels: High, Medium, and Low. Figure 5 presents the distribution of PIC attribute data for all dams in the NZID. Of the 1194 dams in the database, 76 (6%) structures are classified as High PIC, 106 (9%) as Medium PIC, and a further 384 (32%) as Low PIC.

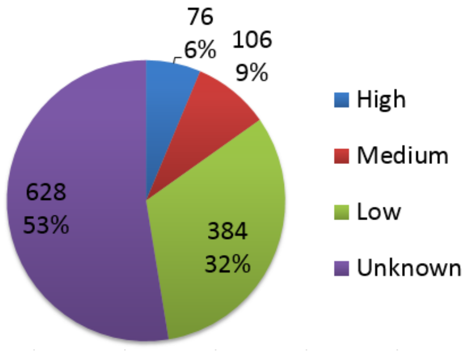


Figure 5: NZID V1.1, PIC classification

Given the inherent societal risk associated with Medium and High PIC dams (182 dams; 15% of all NZID V1.1 structures), these structures are of particular interest to The distribution of Medium and High PIC structures by Type and Age is presented in Figure 6. The majority (73%) of dams are Earth structures, with over three quarters of these constructed prior to 1989. Concrete structures account for 20% of the total Medium and High PIC dataset. Prior to 1960, the majority of Medium and High PIC dams were constructed from concrete.

Overall, 83% of Medium and High PIC structures were built prior to 1989, with just 4% of structures built in the past 15 years. No Medium or High PIC concrete structures have been commissioned since 1990 (Figure 6).

Figure 7 illustrates the distribution of Medium and High PIC structures by purpose and age. Agricultural/pastural/irrigation dams account for a large proportion (30%) of Medium and High PIC structures, with HEPS dams, water supply dams, and detentions dams also featuring prominently (27%, 20%, and 19% of structures, respectively). Most Medium and High PIC Detention dams were constructed between 1960 and 1989. While contributing significantly to the overall dataset, no Medium or High PIC water supply dams have been built since 1990. Since 1990, most new Medium or High PIC dams have been constructed to serve the agricultural/pastural/irrigation sector.

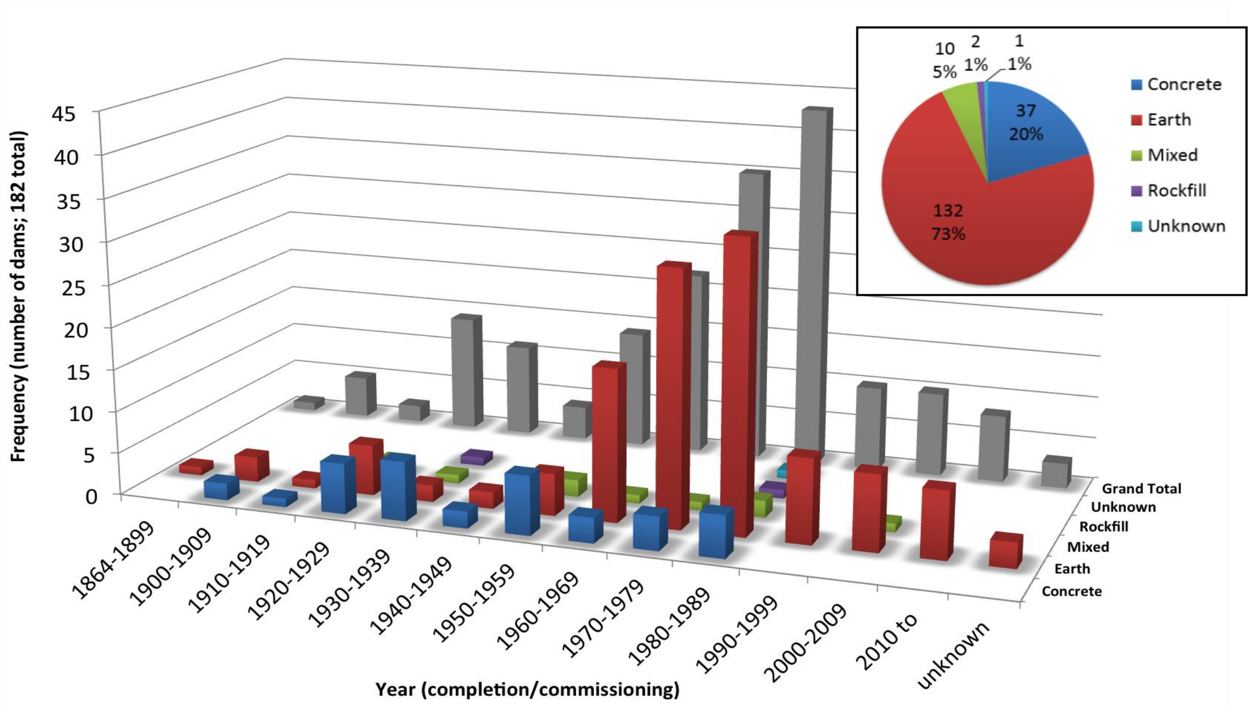


Figure 6: NZID V1.1, Medium and High PIC structures by type and age

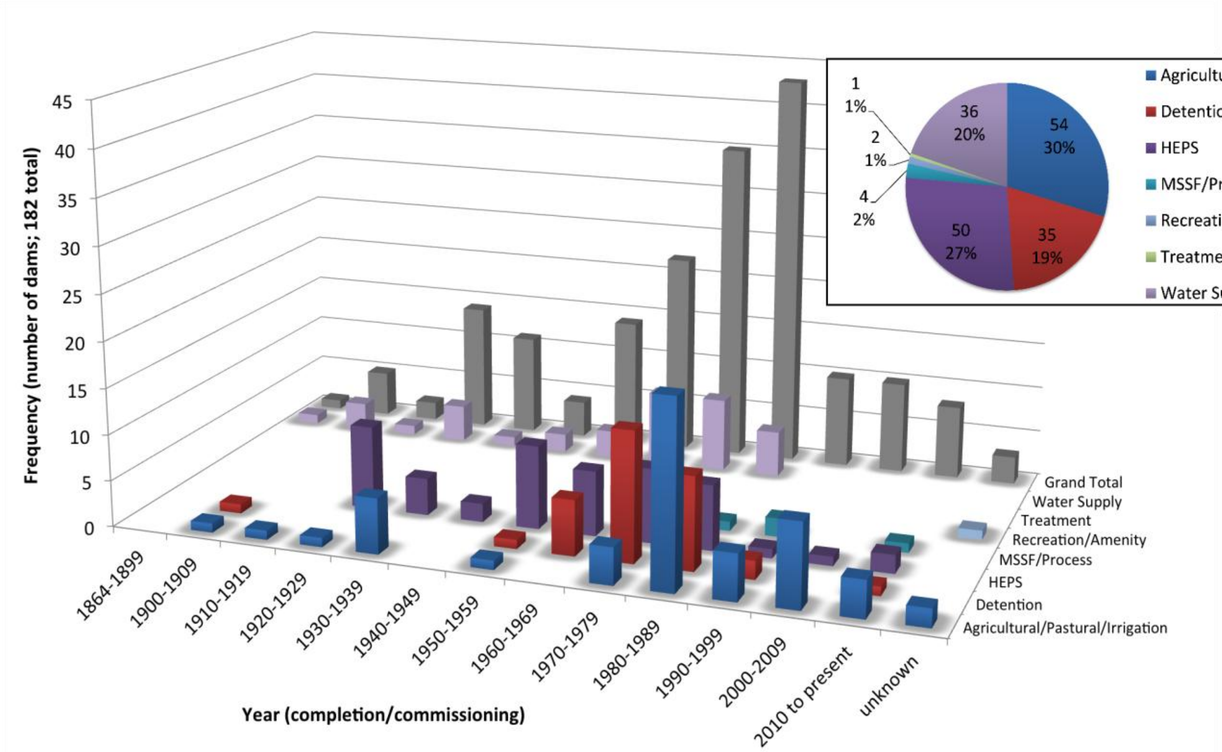


Figure 7: NZID V1.1, Medium and High PIC structures by purpose and age.

Recent dams

Since 2000, dams have been built for a more diverse range of uses (Figure 4). Agricultural/pastural/irrigation dams account for the majority of recent dams built (59% since 2000); however, other 'traditional' purposes such as detention, recreation, water supply, HEPS, and treatment also feature notably (8%, 4%, 4%, 3%, and 3% of builds since 2000, respectively). A number of MSSF/process structures have been constructed since the 1980s, and account for approximately 4% of structures built since 2000. Snowmaking dams were first constructed in New Zealand in the 2000s and, since this time, have accounted for 2% of all structures built. Most Medium and High PIC structures built since 2000 serve the agricultural/pastural/irrigation sector (74%, Figure 7).

General comparisons against international dam datasets

Comparative datasets

Given New Zealand's small population, the local adoption of international dam safety standards, practices, and research outcomes is generally well-justified. However, it is important to acknowledge any fundamental differences in the nature of the local asset portfolio.

A limited number of international dam datasets are available to the public. These datasets feature varying inclusion criteria and report on data synthesis using varying levels of detail. The US National Inventory of Dams (NID) provides a comprehensive dataset of structures greater than 1.8 m in height; however, most other international database concern 'large' dams only. Inclusion criteria are typically determined by height and volume thresholds, as detailed in Table 1. For the purposes of comparison, a subset of the NZID V1.1, containing only large dams, is considered against international Large Dam datasets. This subset of the NZID has been defined using similar criteria to the ANCOLD and ICOLD large dam datasets and includes all structures greater than 15 m in height (Table 1).

Age and height of structures

In general, the datasets show a relatively high proportion of dam completions from the 1950s through 1980s, with a decline in construction during the 1990s (Figure 8). Peak completion periods vary from the 1960s (NID) to the 1980s (NZID). The largest proportion of dams in the ICOLD database were commissioned in the 1970s; while, in Canada, a sustained period of dam construction appears to have spanned from the 1950s to the 1980s. Large dams in the ANCOLD database were similarly completed in consistently large numbers during the 1960s, 1970s, and 1980s. Unlike other datasets, a significant proportion (20%) of structures included in the NZID database have been constructed since 2000 (Figure 8).

Table 1: Comparative dataset properties

	Dataset	Criteria for inclusion (indicative)	Number of Structures
Comprehensive	NZID V1.1	• Height ≥3 m	1,194
	NID (USACE, 2013)	• High Hazard Potential • Significant Hazard Potential • Low Hazard Potential **IF:** ○ Height ≥7.7 m (15 ft) **and** Volume ≥18,500 m^3 ○ Height ≥1.8 m (6 ft) **and** Volume ≥61,700 m^3	Total: 87,359
Large Dams	NZID V1.1 (Large Dams)	• Height ≥15 m, **OR** • Height ≥10 m **and** Volume ≥1x10⁶ m^3	132 12 (Total: 144)
	ANCOLD[1]	• Height ≥15 m, **OR** • Height ≥10 m **and** Volume $\geq 1x10^6$ m^3	490 55 (Total: 545)
	CDA[2]	• Height ≥15 m, **OR** • Height ≥10 m **and** Volume $\geq 1x10^6$ m^3	688 235 (Total: 923)
	ICOLD[3]	• Height ≥15 m **OR** • Height ≥10 m **and** Volume $\geq 3x10^6$ m^3	Total: 58,402
	GRanD V1.1[4]	Volume $\geq 1x10^8$ m^3 (0.1 km^3)	Total: 6,862

[1] Australian National Committee on Large Dams. Truncated dataset; full dataset includes dams that meet additional crest length (≥ 500 m), flood discharge (≥2,000 m^3/s), and design criteria.
[2] Canadian Dam Association (2003). Truncated dataset; full dataset includes dams that meet additional crest length (≥ 500 m), flood discharge (≥2,000 m^3/s), and design criteria.
[3] 2011 Dataset. Criteria as reported for 2007 dataset (ICOLD, 2007)
[4] Database focuses on reservoir properties; comparative analyses not undertaken.

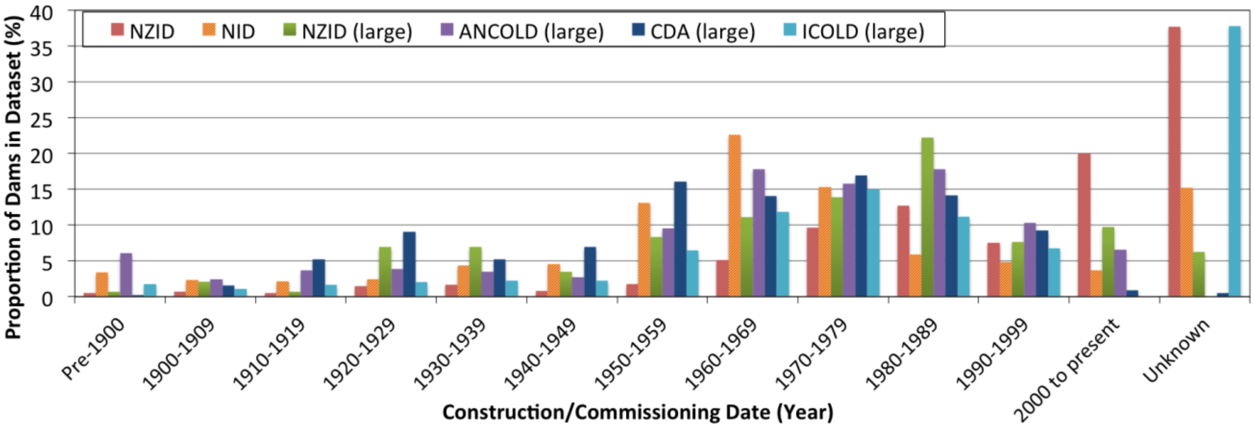


Figure 8: Comparative dam datasets: Year of completion/commissioning

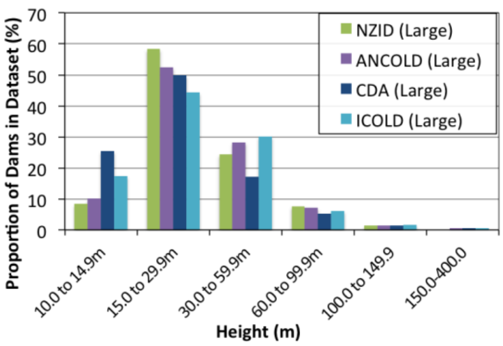


Figure 9: Large dam heights

In the interests of consistency, dam height is compared across databases of 'Large' dams that feature comparative inclusion criteria (namely, NZID V1.1 (large), ANCOLD, CDA, and ICOLD datasets) (Table 1, Figure 9). The New Zealand dataset features proportionally fewer dams in the 10 to 15 m height ranges; yet a larger proportion in the 15 to 30 m bracket. The high proportion of Canadian dams 10 to 15 m in height owes to inclusion criteria: specifically, a number of Canadian dams in the 10 to 15 m height bracket appear to have large reservoir volumes, warranting inclusion in the Large dam dataset (Table 1 criteria). All four large dam datasets demonstrate a similar proportion of dams in the 60 to 100 m and 100 to 150 m height ranges. One should note, however, that no New Zealand dams exceed 118 m in height.

Dam type and purpose

Dam types reported in the US NID and the NZID datasets appear generally similar (Figure 10). Specifically, the majority of dams are earth dams and fewer than 10% of dams are concrete. As mentioned previously, it is expected that a large proportion of the 'Unknown' structures in the NZID are earth structures. In comparison to the US NID, New Zealand possesses a much higher proportion of agricultural/pastural/irrigation dams (9% and 45% of all structures, for the NID and NZID datasets, respectively) and HEPS dams (2% and 7%, respectively). Interestingly, the most common purpose reported in the NID is recreation/amenity (36%); an attribute practically absent in the four Large dam datasets (Figure 11). It is therefore assumed that recreation/amenity structures account for a large number of smaller structures in the United States.

In terms of Large dam datasets, New Zealand has a significantly higher proportion of HEPS dams (37%) when compared to ANCOLD and ICOLD datasets (13% and 20%, respectively; Figure 11); yet far fewer than reported for the CDA inventory (68%). The proportion of large agricultural/pastural/irrigation structures in both New Zealand and Australia (28% and 24%, respectively) appears much lower than for the international ICOLD dataset (49%). Water supply dams account for a modest proportion of Large dams in New Zealand (22%), almost double the proportion of those reported internationally (13%, ICOLD), yet less than half the proportion of water supply dams in the ANCOLD dataset (55%, Figure 11).

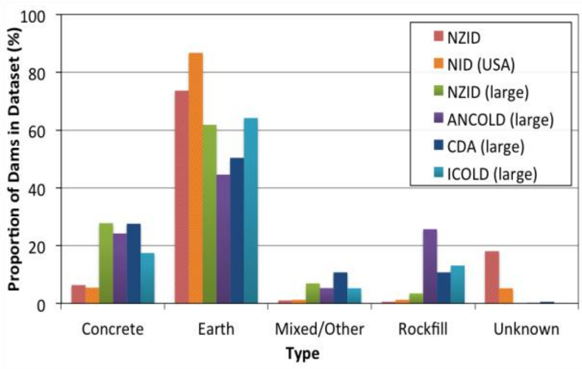


Figure 10: Comparative dam datasets: dam Type

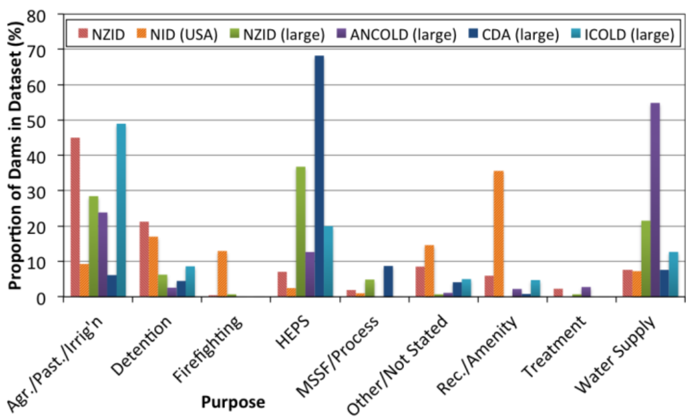


Figure 11: Comparative dam datasets: dam Purpose[1,2,3]

Unique aspects of the New Zealand dam asset base

New Zealand possesses just two dams over 90 m in height. Overall, 7% of structures in the NZID exceed 20 m in height. However, when considering Large dams only (Table 1), the proportions of structures between 30 and 60 m, and 60 and 100m in height are comparable to ANCOLD and ICOLD large dam databases (Figure 9). In comparison to ANCOLD and ICOLD datasets, HEPS structures feature very prominently in the New Zealand asset base (Figure 11). However, the overall proportion of HEPS structures in the NZID is far smaller than in the CDA dataset, owing to diverse water resource needs in New Zealand and relatively large proportions of water supply and agricultural dams in the New Zealand dataset. In contrast, HEPSs are a significant contributor to the Canadian economy; while agricultural and water supply needs are comparatively small due to factors including climate and the Canadian economic/industrial environment (e.g. unlike New Zealand, primary agriculture is not a significant contributor to Canadian GDP).

A greater proportion of New Zealand dams appear to have been constructed more recently than dams built internationally: based on NZID V1.1 data, new dam completions peaked in the 1980s. In contrast, dam completions in the United States appear to have peaked in the 1960s while, internationally, the ICOLD register of large dams shows a peak completion period during the 1970s. Interestingly, a relatively large proportion of structures included in the NZID were constructed in the past 15 years (20% of all structures, in comparison to 7% of NID structures). Rather than demonstrating a unique local trend in dam construction it is likely that, in comparison to international databases, the NZID has simply captured a greater number of smaller and newer dams thanks to recent input from consent authorities.

[1] 'Purpose' refers to primary purpose; except in the case of ICOLD, where primary purpose is not identified for multi-purpose dams. To maintain closest comparability with NZSOLD, ANCOLD, and CDA datasets, multi-purpose structures are therefore not included in comparative analyses presented herein. Instead, data includes only single-purpose ICOLD dams (accounting for 75% of all ICOLD structures for which purpose is defined).

[2] Categorisation criteria may vary between datasets, particularly where purpose is self-reported by individual dam owners. For example, 'Stock Water Supply' or 'Irrigation' structures may inadvertently be categorised as 'Water Supply' structures. Snowmaking is unique to the NZID and has been included in the 'Other' category for the purposes of this analysis. The 'Treatment' category is not specified in NID, CDA, or ICOLD databases; it is possible that these structures may be counted as Water Supply structures. For the purposes of this analysis, 'Concrete' dams include arch, buttress, gravity, and multiple arch structures. 'Others' includes 'Barrages' (as defined in ICOLD).

[3] NID Purpose attributes: 'Recreation/Amenity' includes Fish and Wildlife. Attributes not present in NZID (classified as 'Other' for the purposes of this analysis) include Navigation (204 structures) and Debris Control (422 structures).

Summary and implications

General findings to date

Analysis of the NZID (V1.1) confirms the common assumption that the vast majority of New Zealand dams are Earth structures. Of the 1194 dams included in the inventory, 74% are identified as Earth structures and it is expected that many dams of Unknown type (18%) would be categorised as earth dams also. Earth dams account for 73% of High and Medium PIC structures, over three-quarters of which were constructed prior to 1989. Concrete structures account for 6% of the total inventory, most of which were constructed between 1920 and 1989. No Medium or High PIC concrete structures have been commissioned since 1990.

The peak decade for dam commissioning in New Zealand appears to have been the 1980s, with 13% of inventory structures completed between 1980 and 1989. This finding resolves a commonly-held, yet perhaps misleading, belief that the majority of NZ dams were built over a three or four decade period spanning from the 1940s. With respect to Large Dams, the peak period for dam construction appears to have occurred one to two decades later in New Zealand than internationally. A significant number of dam construction projects have been completed in New Zealand in recent years, with 11% of inventory structures commissioned in the 2000s and an additional 9% commissioned between 2010 and 2015. Agricultural/pastural/irrigation structures account for the majority of recently-completed structures; however, newer dams serve a more diverse range of purposes in comparison to those structures built prior to 1980. Between five and 10 new Medium or High PIC structures have been build each decade (or part thereof) since 1990, according to NZID data. In comparison to ANCOLD and ICOLD datasets, HEPS dams form a relatively large proportion of the New Zealand asset base.

Implications for interest groups

Industry practice and technical interest groups

The prevalence of earth dams in New Zealand, both new and aging, emphasises the need for ongoing training and research in the field of geotechnical dam engineering. Given the decline in construction of concrete dams in recent decades, technical interest groups may also wish to consider future-planning in order to preserve local engineering expertise. Specifically, the current lack of concrete dam design practice may eventually contribute to a loss in local capability at a time where aging concrete infrastructure requires sound engineering input.

While HEPS dams form a large and iconic proportion of the NZ dam portfolio, dams built in recent decades appear to serve increasingly diverse purposes. Accordingly, technical interest groups should ensure that their membership and dissemination channels are appropriately diversified in order to reach new and existing dam owners.

Dam safety and regulatory bodies

While the basic information presented in this paper provides a general overview of dam assets in New Zealand, further detailed analysis of the NZID database could be of great benefit to dam safety and regulatory authorities in New Zealand. The availability of spatial attributes in the NZID (not considered in the present scope) provides an opportunity for detailed spatial risk analysis, e.g. proximal analyses with regard to other infrastructure, hazard regions, residential areas, and zones of land development.

Dam safety groups and regulatory bodies should ensure that they engage in sectors where the largest proportion of new dams are being commissioned, particularly the Agricultural/pastural/irrigation sector. In order to remain visible and relevant to new dam owners, non-traditional sectors (e.g. snowmaking; treatment, MSSF/process) should also be targeted.

Potential Impact Classification (PIC) attributes are unknown for over half the structures in the NZID. The future introduction of a regulatory Dam Safety Scheme in New Zealand would likely require improvements in this area. Furthermore, while the importance of 'large owners' (understood to mean owners responsible for a number of Large and/or High Potential Impact structures) cannot be overstated, the contribution of single-structure owners to the overall asset database should be further quantified. Such information would provide insights as to the need for Dam Safety Management System training in (1) large corporate, and, (2) individual owner, environments.

Research implications

Synthesis of the NZID confirms that earth dams account for the majority of all New Zealand dams, including at least 73% of Medium to High PIC structures. Furthermore, analysis suggests that the majority of NZ earth dams were constructed prior to the development of 'modern' geotechnical filter and internal instability criteria in the late 1980s. Accordingly, the New Zealand dam portfolio reflects global concern that earth dams may possess design deficiencies attributed to the state-of-practice at the time of design. The UCQC Earth Structures Project will begin to address these concerns by way of laboratory research, focusing on the long-term geotechnical performance of New Zealand dam materials. Testing will focus on seepage-induced particle migration in New Zealand earthfill materials under static and seismic loading.

Unlike international studies, where research models are commonly based on structures greater than 150 m height, ongoing geotechnical research undertaken within the UCQC Earth Structures Project will focus on properties considered representative of New Zealand dam assets. Specifically, research parameters such as stress conditions, deformation magnitudes, and seepage characteristics will be typically be modelled on earth dams no greater than approximately 60 m in height.

Ongoing and future analysis

This paper presents cross-sectional findings based on the fundamental categorisation of the 1194 structures in the NZID V1.1. The next stages of the UCQC Characterisation Project involve the use of spatial techniques to improve data quality and define generalised geological and seismic risk characteristics for the NZID dam portfolio.

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