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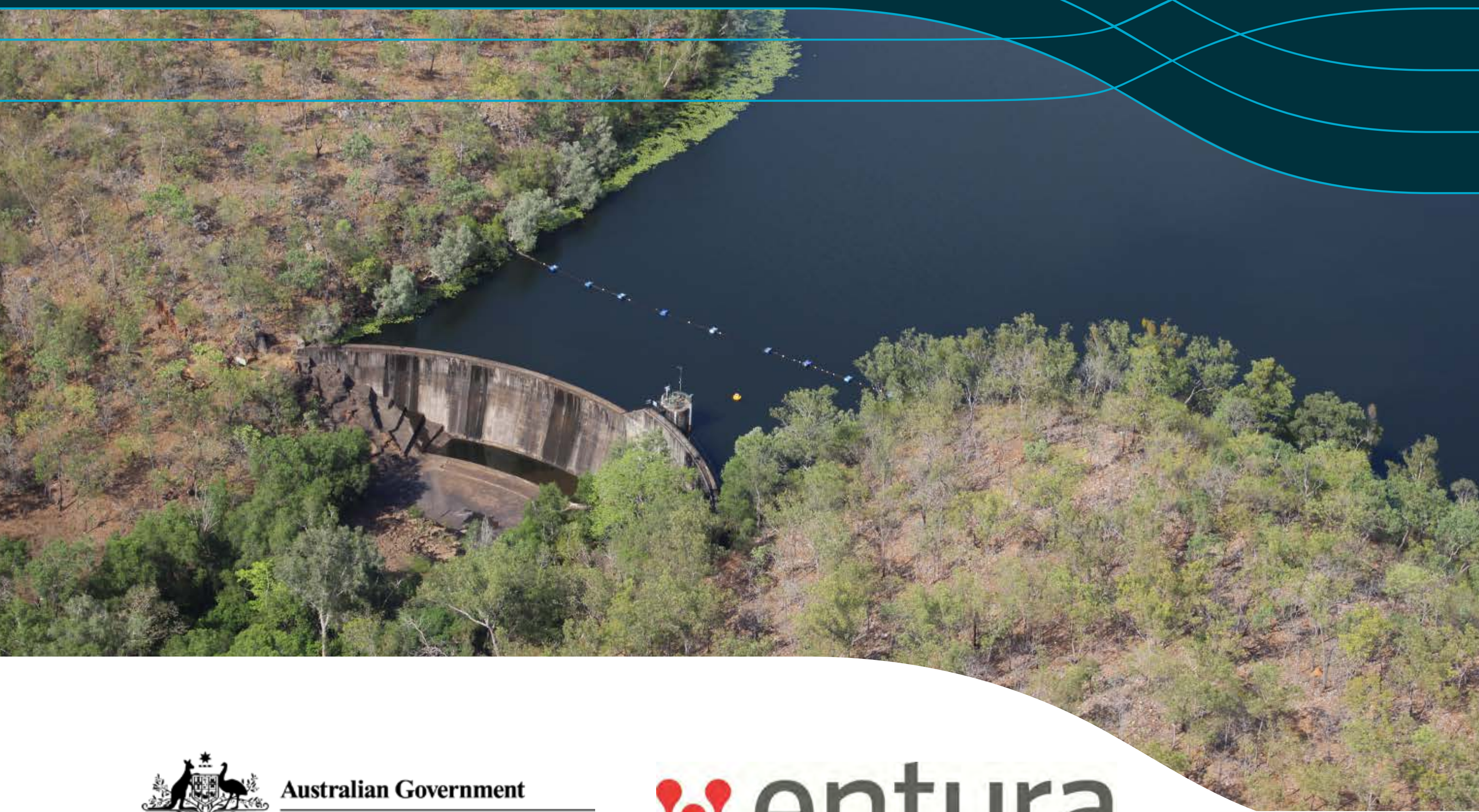
Hydropower study report

A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments

Entura



Australian Government
Department of Infrastructure, Regional Development and Cities

Our research direction

Provide the science to underpin Australia's economic, social and environmental prosperity through stewardship of land and water resources ecosystems, and urban areas.

Land and Water is delivering the knowledge and innovation needed to underpin the sustainable management of our land, water, and ecosystem biodiversity assets. Through an integrated systems research approach we provide the information and technologies required by government, industry and the Australian and international communities to protect, restore, and manage natural and built environments.

Land and Water is a national and international partnership led by CSIRO and involving leading research providers from the national and global innovation systems. Our expertise addresses Australia's national challenges and is increasingly supporting developed and developing nations response to complex economic, social, and environmental issues related to water, land, cities, and ecosystems.

Citation

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CSIRO Northern Australia Water Resource Assessment acknowledgements

This report was prepared for the Department of Infrastructure, Regional Development and Cities. The Northern Australia Water Resource Assessment is an initiative of the Australian Government's White Paper on Developing Northern Australia and the Agricultural Competitiveness White Paper, the government's plan for stronger farmers and a stronger economy. Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government, the Western Australian Government, and the Queensland Government.

The Assessment was guided by three committees:

(i) The Assessment's Governance Committee: Consolidated Pastoral Company, CSIRO, DAWR, DIIS, DoIRDC, Northern Australia Development Office, Northern Land Council, Office of Northern Australia, Queensland DNRME, Regional Development Australia - Far North Queensland and Torres Strait, Regional Development Australian Northern Alliance, WA DWER

(ii) The Assessment's Darwin Catchments Steering Committee: CSIRO, Northern Australia Development Office, Northern Land Council, NT DENR, NT DPIR, NT Farmers Association, Power and Water Corporation, Regional Development Australia (NT), NT Cattlemen's Association

(iii) The Assessment's Mitchell Catchment Steering Committee: AgForce, Carpentaria Shire, Cook Shire Council, CSIRO, DoIRDC, Kowanyama Shire, Mareeba Shire, Mitchell Watershed Management Group, Northern Gulf Resource Management Group, NPF Industry Pty Ltd, Office of Northern Australia, Queensland DAFF, Queensland DSD, Queensland DEWS, Queensland DNRME, Queensland DES, Regional Development Australia - Far North Queensland and Torres Strait

Note: Following consultation with the Western Australian Government, separate steering committee arrangements were not adopted for the Fitzroy catchment, but operational activities were guided by a wide range of contributors.

Acknowledgments: This report was prepared by Indran Pillay (Entura), approved by David Fuller (Entura) and was reviewed by Mohsen Moein (Entura), Cuan Petheram (CSIRO) and Lee Rogers (CSIRO).

Photo: Manton Dam, Adelaide River catchment (NT). Manton Dam has a capacity of 4kW and is the only dam in the Assessment area generating hydroelectric power. Source: CSIRO

Director’s foreword

Sustainable regional development is a priority for the Australian, Western Australian, Northern Territory and Queensland governments. In 2015 the Australian Government released the ‘Our North, Our Future: White Paper on Developing Northern Australia’ and the Agricultural Competitiveness White Paper, both of which highlighted the opportunity for northern Australia’s land and water resources to enable regional development.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and risks of any proposed development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpins the resource security required to unlock investment.

The Australian Government commissioned CSIRO to complete the Northern Australia Water Resource Assessment (the Assessment). In collaboration with the governments of Western Australia, Northern Territory and Queensland, they respectively identified three priority areas for investigation: the Fitzroy, Darwin and Mitchell catchments.

In response, CSIRO accessed expertise from across Australia to provide data and insight to support consideration of the use of land and water resources for development in each of these regions. While the Assessment focuses mainly on the potential for agriculture and aquaculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of development and other interests.

Chris Chilcott

Project Director

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Note: All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined.
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Shortened forms

SHORT FORM	FULL FORM
AMTD	Adopted middle thread distance
CSIRO	Commonwealth Scientific and Industrial Research Organisation
FSL	Full Supply Level
LiDAR	Light Detection and Ranging
MOL	Minimum Operating Level
NSL	Natural Surface Level
PSP	Pumped Storage Project
CAPEX	Capital Expenditure
OPEX	Operational Expenditure

Units

UNITS	DESCRIPTION
km	Kilometres
km^2	Square kilometres
m	Metre
m/s	Metres per second
m^3/s	Cubic metres per second
mAHD	Metres Australian Height Datum
MW	Mega Watt
GWh	Giga Watt Hour
MWh	Mega Watt Hour
kV	Kilo Volt
Mm^3	Million Cubic Metres
$/MW	Dollars per Mega Watt

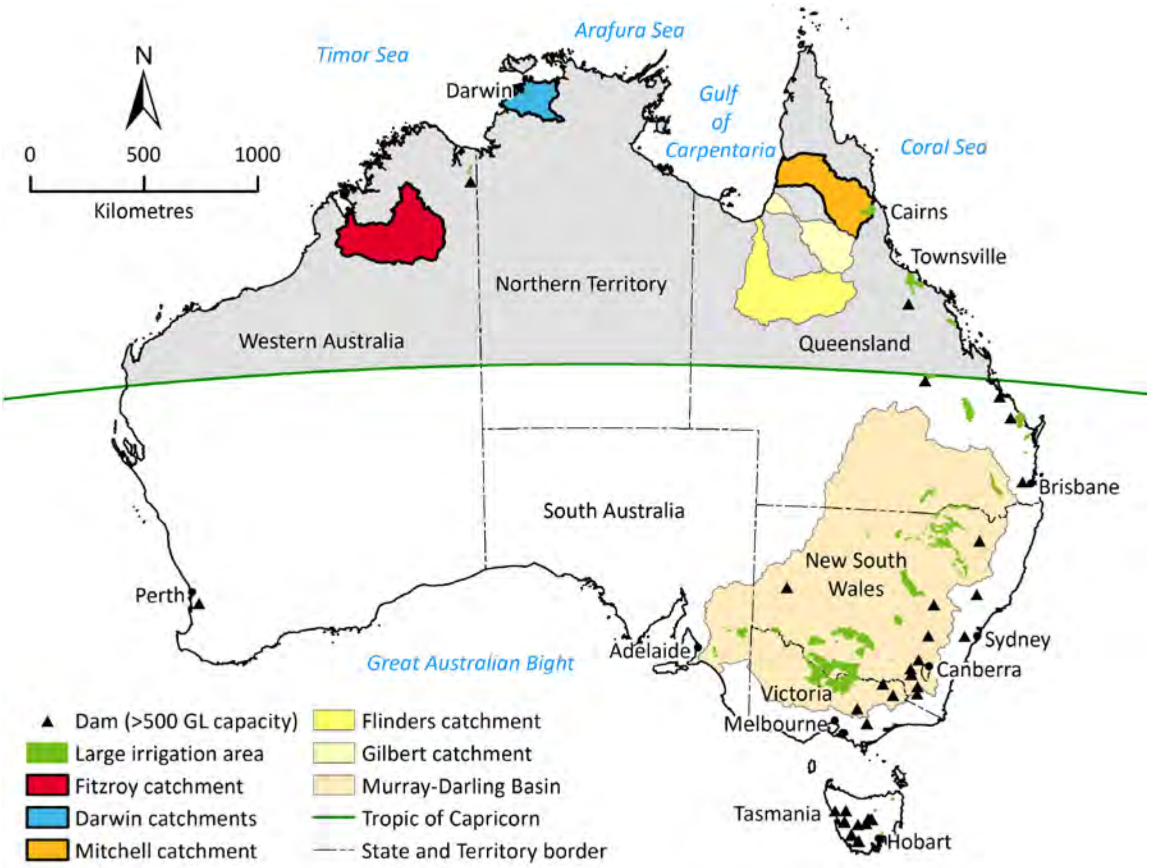
Preface

The Northern Australia Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development in three priority regions shown in Preface Figure 1:

- Fitzroy catchment in Western Australia
- Darwin catchments (Adelaide, Finniss, Mary and Wildman) in the Northern Territory
- Mitchell catchment in Queensland.

For each of the three regions, the Assessment:

- evaluates the soil and water resources
- identifies and evaluates water capture and storage options
- identifies and tests the commercial viability of irrigated agricultural and aquaculture opportunities
- assesses potential environmental, social and economic impacts and risks of water resource and irrigation development.



Preface Figure 1 Map of Australia showing the three study areas comprising the Assessment area
Northern Australia defined as that part of Australia north of the Tropic of Capricorn. Murray–Darling Basin and major irrigation areas and large dams (>500 GL capacity) in Australia shown for context.

While agricultural and aquacultural developments are the primary focus of the Assessment, it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment did not assume a given policy or regulatory environment. As policy and regulations can change, this enables the results to be applied to the widest range of uses for the longest possible time frame.

It was not the intention – and nor was it possible – for the Assessment to generate new information on all topics related to water and irrigation development in northern Australia. Topics not directly examined in the Assessment (e.g. impacts of irrigation development on terrestrial ecology) are discussed with reference to and in the context of the existing literature.

Assessment reporting structure

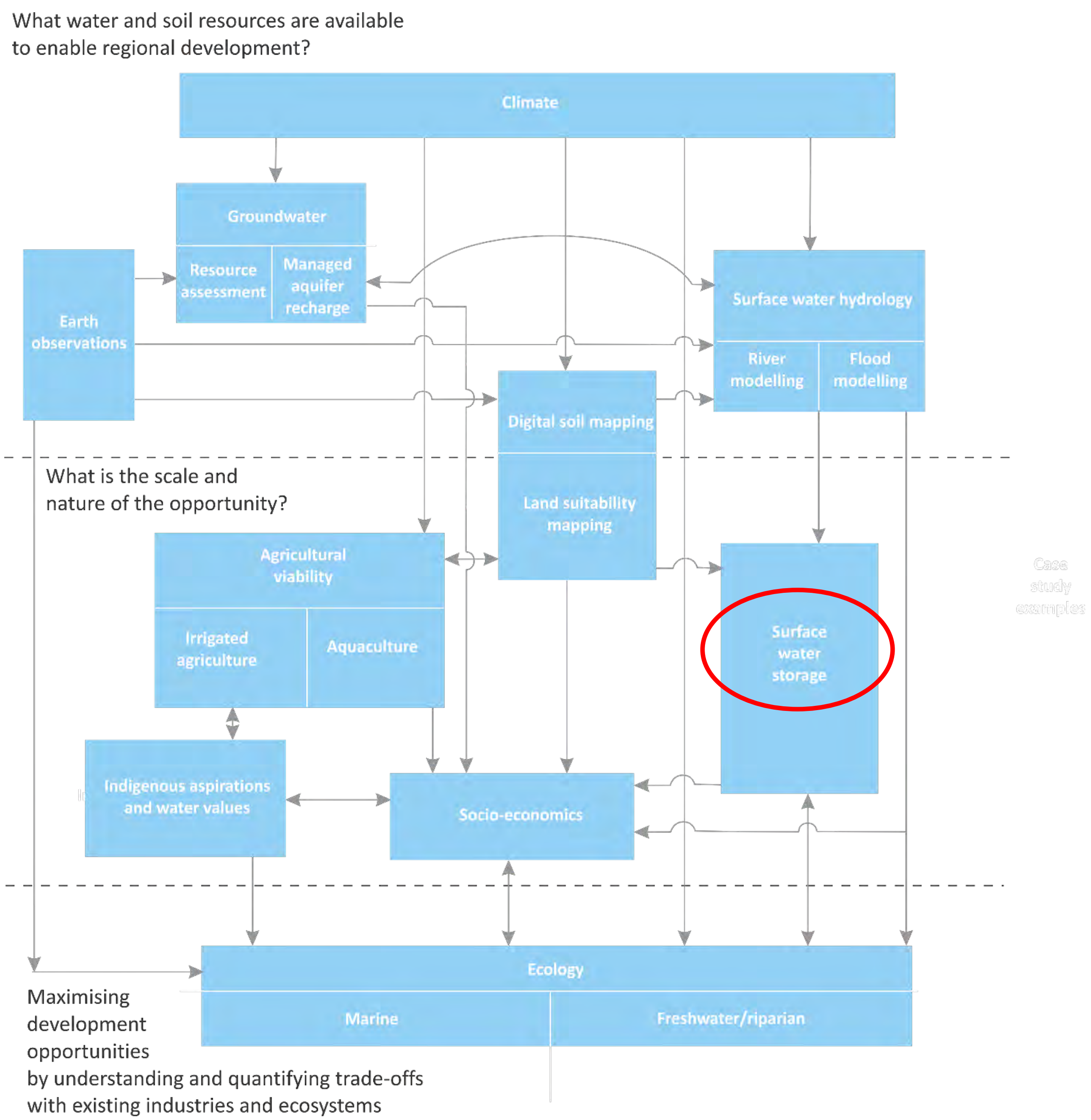
Development opportunities and their impacts are frequently highly interdependent and, consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports most reliably informs discussion and decision concerning regional development when read as a whole.

The Assessment has produced a series of cascading reports and information products:

- Technical reports, which present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the ten activities (outlined below) has one or more corresponding technical reports.
- Catchment reports for each catchment that synthesise key material from the technical reports, providing well-informed (but not necessarily scientifically trained) readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture and other development options.
- Summary reports for each catchment that provide a summary and narrative for a general public audience in plain English.
- Factsheets for each catchment that provide key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable the reader to better access information that is not readily available in a static form. All of these reports, information tools and data products are available online at http://www.csiro.au/NAWRA. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising ten activity groups; each contributes its part to create a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 2 illustrates the high-level links between the ten activities and the general flow of information in the Assessment.



Preface Figure 2 Schematic diagram illustrating high-level linkages between the ten activities (blue boxes)
Activity boxes that contain multiple compartments indicate key sub-activities. This report is a technical report. The red oval indicates the primary activity (or activities) that contributed to this report.

Executive summary

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) have been undertaking a water resource assessment for three priority regions in Australia. The Assessment known as *The Northern Australia Water Resource Assessment* (NAWRA) is focussing efforts in the Fitzroy catchment (WA), the Finniss, Adelaide, Mary, and Wildman catchments (collectively known as the 'Darwin catchments', NT), and the Mitchell catchment (QLD).

As part of the assessment a pre-feasibility study of potential dam sites was undertaken in the Darwin and Mitchell catchments. From this analysis CSIRO nominated six sites for a more detailed desktop analysis, including a pre-feasibility level hydropower assessment. This report pertains to the pre-feasibility level hydropower assessment.

The six sites nominated for a more detailed desktop assessment were:

- Mount Bennettt dam site on the Finniss River, AMTD 80.0 km;
- Upper Adelaide River dam site on the Adelaide River, AMTD 199.2 km;
- Elizabeth Creek dam site on Elizabeth Creek, AMTD 37.2 km;
- Pinnacles dam site on the Mitchell River, AMTD 423.9 km;
- Chillagoe dam site on the Walsh River, AMTD 169.8 km;
- Rookwood dam site on the Walsh River, AMTD 121.3 km.

Entura undertook a hydropower assessment under two release scenarios:

1. Energy generation from irrigation releases and;
2. Energy generation with the dam operating as a hydropower storage dam only.

For each potential dam site, Entura calculated the energy generation using a bespoke hydrology/hydropower model which includes reservoir routing. All inputs to the hydrological model were provided by CSIRO including modelled inflows, direct rainfall and evaporation, downstream irrigation demands, storage and spillway curves and dam arrangements. Entura developed the power station and the high level operational rules required for energy generation.

For each site the energy generation under each scenario was estimated over four different design discharge values selected from the reservoir inflow curve. The selected design discharge values are the percentage of time that the discharge is expected to be exceeded. For this study the 10^{th}, 30^{th}, 50^{th}, and 70^{th} percentile time exceedance discharges were selected.

The power generated from each scheme is proposed to be grid connected. In the Darwin catchments (NT) it was assumed the Mount Bennett and Upper Adelaide potential dam sites were connected to the NT distribution grid. These potential dam sites are located near existing distribution sub-stations which could be potential connection points pending capacity enquiries.

The hydropower assessment was undertaken under two release scenarios

1. energy generated from irrigation releases only (Irrigation) and;
2. assuming energy was generated as the dam operating as a hydropower storage dam (Hydro Power).

The table below summaries the findings of the assessment for the dam sites located in the Darwin catchment; including estimated capital expenditure (CAPEX[1]) to implement the hydropower development at each site for each of the various design discharges.

Executive Summary Table 2 Summary of hydropower assessment for the Darwin catchments

DAM SITE	PARAMETER	UNIT	P10	P30	P50	P70
Bennett	Rated Discharge	[m³/sec]	47.90	8.90	1.90	0.23
	Installed Capacity	[MW]	4.4	1.0	0.2	0.03
	Hydro Power	[MWh]	14,607	7,576	1,814	215
	Irrigation	[MWh]	3,931	3,396	992	113
	CAPEX	[$million]	$23	$6	$1.25	$0.14
	OPEX	[$/Year]	$695,395	$185,102	$37,482	$4,111
Upper Adelaide	Rated Discharge	[m³/sec]	16.13	2.97	0.79	0.17
	Installed Capacity	[MW]	2.5	0.5	0.1	0.03
	Hydro Power	[MWh]	12,698	4,023	1,042	206
	Irrigation	[MWh]	4,983	2,754	902	179
	CAPEX	[$million]	$13	$2.18	$0.48	$0.12
	OPEX	[$/Year]	$394,108	$65,534	$14,548	$3,616

The four potential dam sites in the Mitchell catchment are located at the end of the National Electricity Market (NEM) region, approximately 130 km from Cairns, and were assumed to connected to the NEM. Within the Mitchell catchment the Mitchell River and Elizabeth Creek potential dam sites are located approximately 60 km from the Mulligan Highway which has a three phase distribution line adjacent to it. Both projects could connect to the grid via this distribution line, however, a new sub-station to allow for the 'cut-over' to the NEM will be required to be built. The Walsh River sites have an opportunity to connect to the local distribution network in the town of Chillagoe.

Executive Summary Table 2 Summary of hydropower assessment for the Mitchell catchment

	PARAMETER	UNIT	P10	P30	P50	P70
Mitchell	Rated Discharge	[m³/sec]	107.10	16.33	7.09	3.63
	Installed Capacity	[MW]	44.48	6.93	3.07	1.56
	Hydro Power	[MWh]	257,926	52,010	22,886	11,682
	Irrigation	[MWh]	104,902	56,837	24,523	12,361
	CAPEX	[$million]	$132	$19	$13.8	$5.3

[1] CAPEX estimates are in Australian dollars (AUD) and are subject to significant variation if transmission capacity is limited and new 66 kV transmission lines are required.

	PARAMETER	UNIT	P10	P30	P50	P70
	OPEX	[$/Year]	$3,957,812	$562,819	$413,596	$158,588
Elizabeth	Rated Discharge	[m³/sec]	6.45	0.77	0.18	0.10
	Installed Capacity	[MW]	1.70	0.21	0.05	0.03
	Hydro Power	[MWh]	9,867	1,589	413	215
	Irrigation	[MWh]	2,802	1,731	443	228
	CAPEX	[$million]	$19	$2.2	$0.50	$0.30
	OPEX	[$/Year]	$563,451	$66,968	$14,936	$9,009
Walsh 03	Rated Discharge	[m³/sec]	42.49	4.84	0.82	0.11
	Installed Capacity	[MW]	13.58	1.65	0.28	0.04
	Hydro Power	[MWh]	56,768	12,246	2,085	269
	Irrigation	[MWh]	27,768	14,141	2,114	260
	CAPEX	[$million]	$58	$7	$0.98	$0.12
	OPEX	[$/Year]	$1,730,927	$199,933	$29,453	$3,548
Walsh 04	Rated Discharge	[m³/sec]	53.53	6.20	1.08	0.14
	Installed Capacity	[MW]	23.35	2.92	0.51	0.07
	Hydro Power	[MWh]	147,847	21,785	3,885	350
	Irrigation	[MWh]	48,336	23,894	4,187	368
	CAPEX	[$million]	$78	$9	$1.36	$0.16
	OPEX	[$/Year]	$2,330,086	$274,702	$40,663	$4,734

Entura has estimated the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for each discharge scenario including transmission and sub-station costs. Based on the estimated CAPEX, the cost per MW installed ranges from $ 2.3 – $ 11 million/MW over all sites and discharge scenarios. This excludes the Elizabeth sites which are substantially more expensive (~$9.7 - $ 11 million/MW) due to significant transmission line costs.

This study has revealed that for the irrigation energy generation scenario the Darwin catchment potential dam sites have significantly more variability in energy production than the Mitchell catchment potential dam sites. This variability is due to the quantum of inflows compared to the variable irrigation demand over the year.

Modelling of hydropower only operations provides less variability in energy generation as turbines are operated at the most efficient discharge rather than meeting downstream irrigation demands. As turbines are operated efficiently, this mode of operation also provides a greater quantum of energy.

None of the six sites under either discharge scenario could provide a constant energy profile, representative of baseload hydropower.

The most significant aspect of these potential developments is the distance from any existing electrical distribution infrastructure. The cost of this infrastructure dominates the cost of hydropower stations due to the small installed capacities for each design discharge.

Contents

Figures

Tables

Part I Main report

1 Introduction

Entura is a specialist renewable energy and water consultancy that has a strong track record of developing renewable energy projects in Australia and overseas.

CSIRO have been working with the Australian Government, jurisdictions, and stakeholders to deliver water resource assessments for three priority regions in northern Australia. The Northern Australia Water Resource Assessment, referred to as the Assessment, is focussing efforts in the Fitzroy catchment (WA), the Finniss, Adelaide, Mary, and Wildman catchments (collectively referred to as the Darwin catchments, NT), and the Mitchell catchment (QLD).

The overarching objective of the Northern Australia Water Resource Assessment is to identify the opportunities by which water resource development may enable regional economic benefit, and the risks that may attend that opportunity. The project builds on the National Water Resource Assessment program, the Flinders and Gilbert Agricultural Resource Assessment, and a broader body of work contributing to the sustainable development of northern Australia.

As part of the Assessment, a pre-feasibility assessment of potential dam sites was undertaken in the Darwin and Mitchell catchments. Six sites were then 'short-listed' for a more detailed desktop analysis, including a pre-feasibility level hydropower assessment. As explained in the companion technical report on surface water storage, Petheram et al., (2017), the 'short-listed' sites were selected on the basis of the topography of the dam axis, geological conditions, proximity to suitable soils and water yield, and represent some of the more promising large in-stream and off-stream water storage options in the Darwin and Mitchell catchments. In selecting sites for 'short-listing' the potential for hydropower generation was not specifically considered. However, it should be noted that two promising sites, AROWS (Darwin catchments) and Nullinga (Mitchell catchment) were not selected for short-listing on the basis that feasibility level investigations of these two sites were being undertaken in parallel with the Assessment.

This report pertains solely to the pre-feasibility level hydropower assessment undertaken on the six short-listed sites and is structured as follows. The remainder of this section outlines the scope of work, key limitations and exclusions and provides an overview of hydro-electric power and pumped storage. Section 2 describes and shows the location of the potential dam sites. Section 3 details the data and methods used in the hydropower analysis. The power generation results under hydropower only and irrigation release scenarios are provided in Section 4. Section 5 comprises a summary and conclusions. The report contains two appendices. The first contains charts of energy generation for each potential dam site under each release scenario. The second contains inflow, demand and spill duration curves.

1.1 Scope of work

The scope of work for this study was to:

- undertake an hydropower potential assessment and develop cost estimates for the six nominated sites;
- prepare an hydropower opportunities and challenges paper;
- prepare a pumped storage opportunities and challenges paper.

1.2 Limitations and exclusions

The following limitations and exclusions apply to this study:

- This study was undertaken as a desktop study only with no site visits or site specific investigations;
- CSIRO nominated all dam configurations and locations
- Energy modelling was completed under two scenarios only:
  - Operating the dam for hydropower purposes only
  - Operating the dam for irrigation purposes
- No turbine optimisation was undertaken (although a range of potential turbine configurations were considered).
- Energy generation was solely based on irrigation demand or the availability of water for generation. No consideration was given to energy market demands.
- No energy revenue modelling was undertaken.
- No geotechnical investigations in support of a potential dam or power station was undertaken as part of this desktop study.
- Each scheme is to be grid connected with any captive generation excluded due to unknown onsite energy demand.
- All CAPEX and OPEX costs are based on typical unit cost rates in the industry. Transmission line and substation cost estimates are less certain than other estimates due to the need for more detailed investigations matching energy supply and capacity of existing networks.

Further limitations on the study are identified in the body of this report.

1.3 Hydro-electric power

Hydro-electric power generation (or simply hydropower) has been used for over 135 years to convert the kinetic energy of water to electrical energy. Hydropower was enabled by the invention of turbines and generators in the 19th century and was rapidly developed around the world during the 20th century.

Hydropower is highly scalable with systems able to be designed to meet the needs of a small village through to large projects that meet regional or national energy needs. It is the world’s largest source of renewable energy.

The generation of hydropower is a function of hydraulic head and flow. The gross head is the maximum possible difference in elevation between the headwater (H.W.) of the reservoir and the tailwater (T.W.) during which the turbine unit will operate. Net head is the gross head minus all the headloss parameters in the system. Net head on the turbine is the head available for producing power.

Traditionally there are two broad types of hydropower:

- **Run-of-river hydropower** developments typically channel water through a canal, tunnel or pipe (penstock) to spin one or more turbines. These schemes typically have little or no water storage and are dependent on a consistent river flow to provide a continuous supply of electricity. They contribute to meeting baseload electricity demand.
- **Storage hydropower** uses a dam to store water and releases the water through canals, tunnels or penstocks to one or more turbines. Storage hydropower can be used to meet baseload and/or peak electricity demands. Storage projects provide variable amounts of storage volume and can also be optimised to increase the potential energy of water entering penstocks by raising the water surface elevation.

Most conventional hydroelectric plants include at least the following components:

- **Dam structure:** Which controls the stream flow, stores and raises the water level to maximise energy generation. The reservoir behind the dam is in effect stored energy. In addition to hydropower, reservoirs might be used for a range of other purposes such as irrigation, flood control, recreation and potable water supply.
- **Water conveyance system:** In order to transfer water from the reservoir to the power station, canals, pipes, and/or tunnels may be used. The pressurised section that leads to the powerhouse is called a penstock.
- **Power station (or powerhouse):** The powerhouse accommodates the electro-mechanical elements that convert kinetic energy to electricity. These elements include turbines, generators, valves and other services. Powerhouse may be underground or on the surface depending on the local topography and capacity to generate hydropower.
- **Turbine:** Much like a waterwheel, falling water spins the turbine blades converting kinetic energy of into mechanical energy.
- **Generator:** The generator is connected to the turbine shaft so spins when the turbine spins. The generator converts the mechanical energy from the turbine into electric energy.
- **Switchyard:** In most cases, the energy generated needs to be converted into a form that can be readily delivery to the electricity grid. This is achieved using transformers and other components.
- **Transmission lines:** Conduct electricity from the hydropower plant to where it is needed.

In Australia, hydropower schemes are typically categorised according to their installed capacity. Schemes with less than 1 Mega Watt (MW) installed capacity are called Micro Hydro, those between 1 and 10-30 MW are categorised as Mini Hydro, and above that schemes are categorised as Large Hydro.

The economics of hydropower developments is governed by the type of end use (e.g. small scale vs large scale power generation, multiple use vs single use storages), the variability of flows and base flows, the availability of efficient dam sites, and the elevation through which water can fall to generate power.

In northern Australia, and specifically in the Mitchell and Darwin catchments, there are significant challenges for reliable hydropower development including the seasonal or ephemeral nature of some rivers, the high annual variability in wet season runoff, the relatively flat landscapes; except in the headwaters of some catchments, and the distance to the existing electricity grid. These features indicate that substantial storages would be required to support a large enough installed capacity which could provide a reliable hydro-electric development and be commercially viable to be connected to the National Electricity Grid (NEM).

An alternative to a NEM connected development is an isolated grid development. An isolated grid would require substantially more electrical infrastructure in order to maintain system stability and reliability in the absence of the NEM.

For the purposes of this project, dam sites were identified by CSIRO primarily for agricultural production rather than maximising hydropower generation. If hydropower potential is to be investigated in more detail, a more targeted study is required with a detailed view of downstream energy demand and the type of electricity grid interconnection required. Depending on how hydropower reservoirs are managed, there may be opportunities for downstream irrigation developments.

1.4 Pumped storage plants

Pumped Storage Plants (PSPs) have been in operation since the beginning of 20th century in the United States and Europe. According to the International Hydropower Association, in 2016 PSPs provided 97% of global energy storage capacity.

Basically, a PSP has two reservoirs linked together with waterways and a powerhouse located in between. Energy is stored by pumping water from the lower reservoir to the upper reservoir and is electricity is generated in the reverse order as illustrated below.

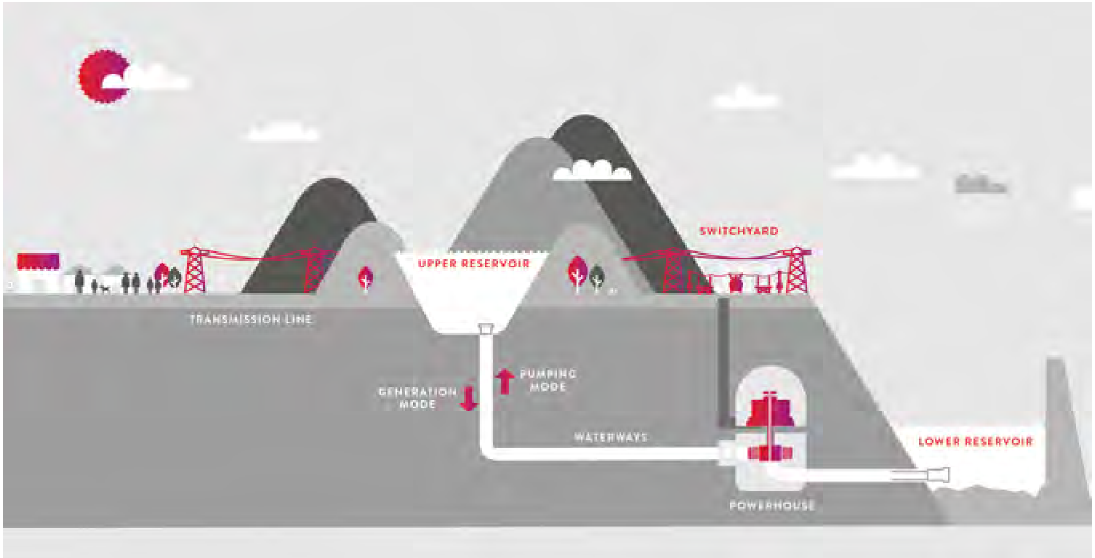


Figure 1-1 Schematic diagram of a pumped storage operation

In some cases nowadays, rather than utilising separate pumps and turbines, highly efficient low-cost reversible turbines can be used. The selection of these turbines is site specific and also related to the required operation strategy of the plant. For instance, if a very fast response is required then special ternary turbine pumps sets could be adopted although relatively significant extra cost is involved compared to the conventional reversible turbines. The design of PSPs requires careful engineering to optimise the design and cost benefit.

Pumped storage power schemes can often be retrofitted to conventional hydropower schemes to maximise the energy generated from existing reservoirs.

It is now widely understood that the inherent inertia of PSPs can assist the stability of power grids by levelling out fluctuations in the availability of wind and solar energy generation, and helping to regulate both voltage and electrical frequency across the network.

Pumped storage hydropower has a real and growing role to play as Australia transitions to increased renewable energy generation, with both storage issues and network stability challenges that come with wind and solar penetration. Based on the Hydropower Status Report (IHA, 2016), total hydropower installed capacity in Australia is 8,790 MW out of which 740 MW is pumped storage.

PSP developments in the Mitchell and Darwin catchments are feasible from an engineering perspective however the purpose of PSP developments (energy storage/grid stability provisions) makes developing a commercially viable PSP within these catchments difficult as at this stage there is no requirement for stored energy. In addition, the project locations have large geographic distances from the NEM which is not favourable.

2 Potential dam sites

As part of the Assessment a pre-feasibility assessment of potential dam sites was undertaken in the Darwin (Northern Territory) and Mitchell (Queensland) catchments. As part of this analysis CSIRO nominated six sites for a more detailed desktop analysis, including a pre-feasibility level hydropower assessment. This report pertains to the pre-feasibility level hydropower assessment.

Entura undertook a hydropower assessment under two release scenarios:

- Energy generation from irrigation releases only, and
- Energy generation with the dam operating as a hydropower storage dam only.

The dam designs and configurations were completed by CSIRO and provided to Entura. Entura has not undertaken any review or assessment of the dam arrangement works, including their appurtenant structures. The dam sites are referred to in this report according to their analysis name as shown in Table 2-1.

Table 2-1 Six short-listed potential dam sites nominated by CSIRO for a more detailed desktop assessment in the Darwin and Mitchell catchments

OFFICIAL NAME	ANALYSIS NAME
Mount Bennett dam site on the Finniss River, AMTD 80.0 km	Mount Bennett
Upper Adelaide River dam site on the Adelaide River, AMTD 199.2 km	Upper Adelaide
Pinnacles dam site on the Mitchell River, AMTD 423.9 km	Mitchell
Elizabeth Creek dam site on Elizabeth Creek, AMTD 37.2 km	Elizabeth
Chillagoe dam site on the Walsh River, AMTD 169.8 km	Walsh 03
Rookwood dam site on the Walsh River 121.3 km	Walsh 04

The location of the Mount Bennett and Upper Adelaide potential dam sites, their catchment areas and their potential reservoirs at the nominated full supply level are shown in Figure 2-1.

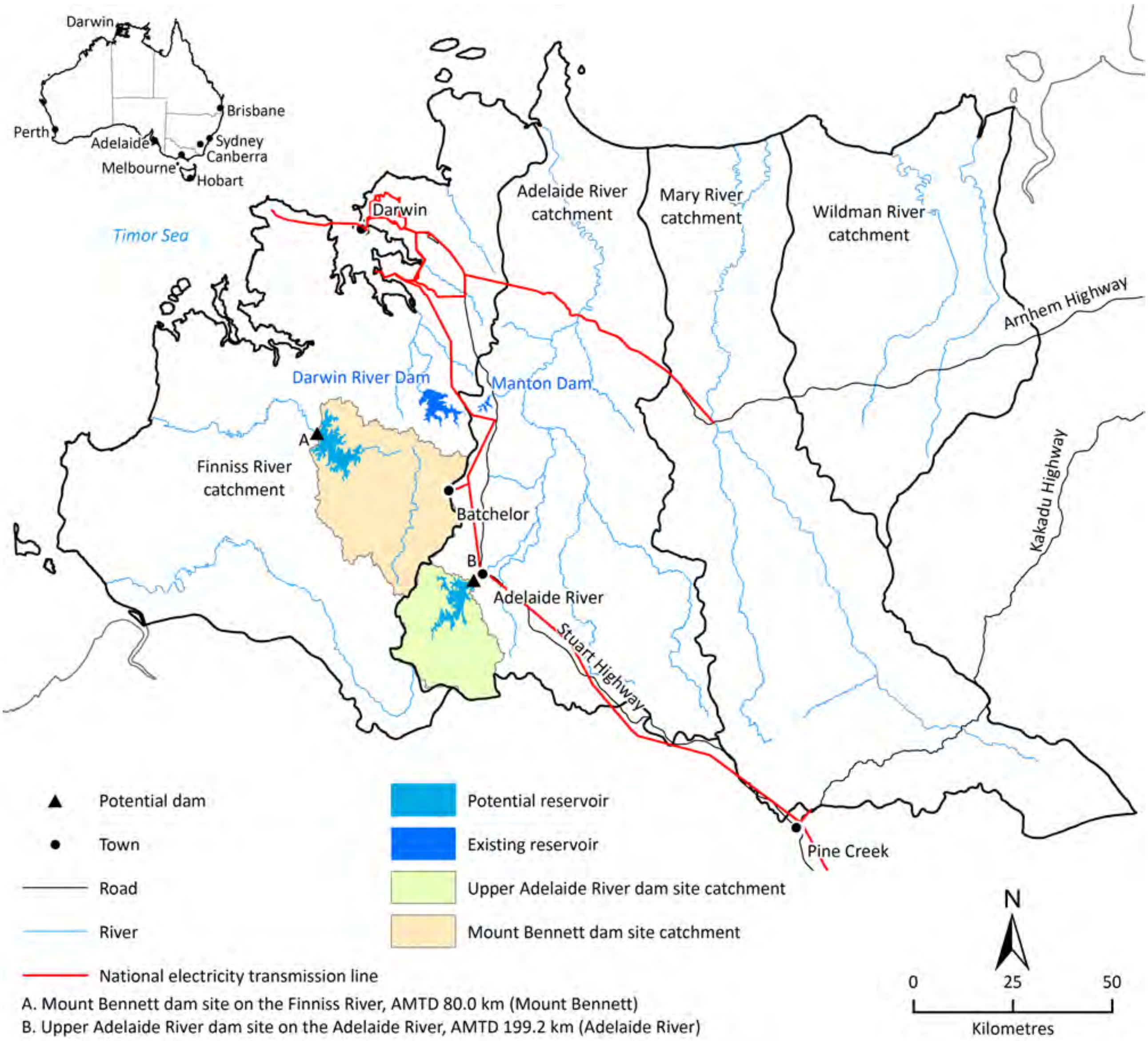


Figure 2-1 Short-listed potential dam site in the Darwin catchments
Potential reservoir extent shown at the nominated full supply level.

The location of the Mitchell, Elizabeth Creek, Walsh 03 and Walsh 04 potential dam sites, their catchment areas and their potential reservoirs at the nominated full supply level are shown in Figure 2-2.

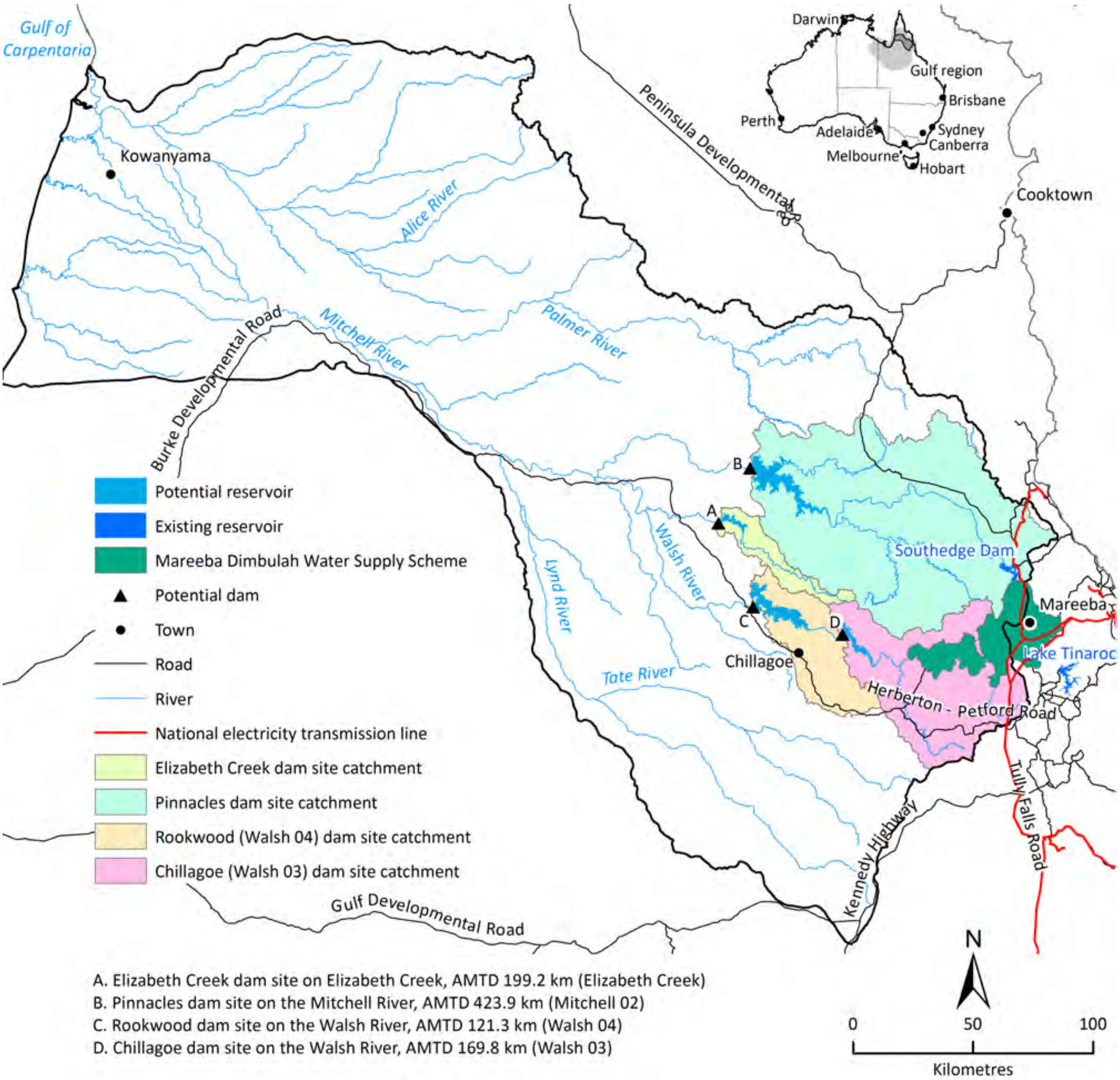


Figure 2-2 Short-listed potential dam sites in the Mitchell catchment
Potential reservoir extent shown at the nominated full supply level.

3 Data and methods

This chapter provides a summary of the methods used to model and assess hydropower generation opportunities. The hydropower assessment was undertaken under two release scenarios:

1. Energy generation from irrigation releases and;
2. Energy generation with the dam operating as a hydropower storage dam only.

3.1 Hydrological modelling and other inputs

CSIRO developed a daily hydrological model for the Assessment (see companion technical report on river model calibration, Hughes et al., 2017). Model outputs were provided by CSIRO as a daily time series of reservoir inflows – 125 years for potential dam sites; except Elizabeth which had 115 years of data, as the runoff data was sourced from a different hydrological model. In addition, associated daily rainfall and potential evaporation data were supplied by CSIRO. Supplied data was assumed to be fit for purpose and used for hydropower modelling. No independent validation of supplied data was undertaken by Entura.

In addition to the above information, CSIRO also provided area – volume curves, the full supply level (FSL) of each storage, and related spillway discharge tables. Points on the storage curves and spillway discharge curves were checked for continuity/consistency. No other checks were undertaken by Entura prior to the adoption of this information for hydropower modelling.

Table 3-1 Technical summary of dam sites

	UNIT	MOUNT BENNETT	UPPER ADELAIDE	ELIZABETH	MITCHELL	WALSH 03	WALSH 04
FSL	[mAHD]	28	80	235	240	380	295
MOL	[mAHD]	22	67	213	196	348	256
Environmental flow[2]	[m^3/sec]	-	-	-	-	-	-
Catchment area	[km^2]	1187	616	580	7728	3423	4855
Active storage volume	[Mm^3]	307	273	140	2289	562	1274
Turbine setting @ powerhouse	[mAHD]	9	58	199	183	335	235
Maximum tailwater elevation	[mAHD]	11	60	201	185	337	237

For each dam site CSIRO provided representative downstream demand patterns over a 125-year record. These demand patterns are broadly representative of the pattern of irrigation releases required for a perennial or double rotation crop (refer to Table 3-2). Based on these irrigation releases power generation was estimated for each site.

[2] Note: CSIRO advised that environmental flows were not to be considered in this desktop hydropower assessment. Subsequent more detailed hydropower modelling may need to take environmental water releases, constraints on turbine operations, and potentially in-storage environmental sensitivities into consideration.

Table 3-2 Mean monthly downstream water demand [mm^3]

MONTH	MOUNT BENNETT	UPPER ADELAIDE	ELIZABETH	MITCHELL	WALSH 03	WALSH 04
January	0.00	0.00	0.12	2.81	0.87	1.29
February	0.16	0.05	0.08	1.79	0.55	0.82
March	0.31	0.10	0.11	2.44	0.75	1.12
April	1.39	0.46	0.16	3.76	1.16	1.73
May	2.36	0.79	0.18	4.04	1.24	1.85
June	2.14	0.71	0.16	3.76	1.16	1.73
July	2.22	0.74	0.16	3.65	1.13	1.68
August	2.51	0.84	0.21	4.83	1.49	2.22
September	2.27	0.75	0.16	3.73	1.15	1.71
October	0.74	0.25	0.07	1.66	0.51	0.76
November	0.61	0.20	0.18	4.18	1.29	1.92
December	0.29	0.10	0.19	4.42	1.36	2.03
Annual Average	**1.25**	**0.42**	**0.15**	**3.42**	**1.05**	**1.57**

3.2 Power station siting and turbine selection

Hydropower power potential was evaluated under the assumption that the power stations at each dam site are located at the toe of dam with a short 100 m penstock and turbine inlet.

The turbine combination for a range of design discharges was selected as follows:

- A rated design discharge was selected from the reservoir inflow duration curve.
- From the dam arrangement supplied by CSIRO and the selected turbine setting the gross head and net head available was calculated. For this study it was assumed the turbine setting was equal to the river bed elevation downstream of the reservoir. This assumption would require some excavation to accommodate the draft tube and other powerhouse auxiliary services.
- The rated discharge, gross and net head parameters were used as inputs to TURBNPRO™ software to consider appropriate turbine configurations. TURBNPRO is a hydraulic turbine sizing and technical data development program. The User is required to input the hydroelectric site conditions, desired operating parameters and desired equipment arrangement. Based upon characteristics typical of hydraulic turbines, TURBNPRO calculates the sizes, speeds, setting limitations, dimensional and performance characteristics of turbine solutions which would satisfy the project requirements. TURBNPRO is not intended for use as a design aid to design or manufacture hydro turbines.
- Once the appropriate turbine solution was selected and configured in TURBNPRO, the turbine discharge rating curve was extracted as a turbine 'hill curve[3]'.
- The hill curve efficiency ranges for a given head and flow was then used in Entura's hydropower model to calculate optimal energy generation under each modelling scenario.

[3] The turbine hill curve sets out the broad operating parameters for each turbine. The maximum and minimum head and flow range is plotted including indication of the likely cavitation ranges which should be avoided during operations.

The rated design discharge for each turbine unit was sized for the following daily inflow time exceedance percentiles[4]: 10%, 50%, 30% and 70%. The abbreviations used to describe these flows in the remainder of the report are P10, P30, P50 and P70.

For each potential dam site one or two turbine units were considered contingent on the flow and head available for each inflow percentile (refer to Table 3-3).

3.3 Tailwater levels

For each turbine size considered, a constant downstream power station tailwater was estimated based on the rated, maximum and minimum turbine discharges. Tailwater elevations were calculated using a one dimensional hydraulic model (HECRAS™) of the reach downstream of each potential damsite. River cross-sections and profiles were extracted from the *ASTER Global Digital Elevation Model™*. Dynamic modelling of the tailwater is not part of this study and as such energy generation from reservoir spill events are not considered. This operating rule has been adopted as during spill events the power station is at risk of flooding and would be required to shut down. In addition energy generation is much less efficient due to lower net head during high tailwater events[5].

3.4 Sedimentation

After discussion with CSIRO, Entura was advised to assume zero sedimentation for the purposes of this study. This is equivalent to assuming that the dead storage in each reservoir is sufficient to capture all residual bed or suspended sediment load arriving at the storage site. Preliminary desktop estimates of sediment infill for each of the six nominated sites are provided in the companion technical report on surface water storage, Petheram et al., (2017).

Under a more detailed feasibility level hydropower analysis it is common place to undertake a full sedimentation analysis to ensure that intakes and water levels are not impacted over the life span of the project.

For the purposes of the current study it was assumed that the dead storage level in each reservoir would lie at a height of 5 m above the river bed.

3.5 Minimum operating level

The minimum operating level (MOL) is the lowest elevation that water can be released for either irrigation or hydropower purposes. Typically, the MOL is nominally set at a height above the invert level of the intake structure which allows for sufficient intake submergence. For this study CSIRO defined the MOL for each dam site. An assessment of the selected MOL and the dead storage level was not part of this study.

[4] Time exceedance percentiles refer to the percentage of time that a specific flow is expected to be exceeded.
[5] Some model runs with energy generation under spill were undertaken for sensitivity testing. Results did not differ substantially from those presented in this report.

3.6 Power station intake

The arrangement or type of intake for each dam was not investigated. Given that CSIRO has designed all of the dams as roller compacted concrete (RCC), it was assumed that the intake structure is located in the dam body with buried pipe in the dam and the penstock running towards the powerhouse.

3.7 Power generation modelling

For each potential dam site, a separate single storage model was developed using a bespoke Entura power generation tool. The model incorporates water balance modelling and storage routing. It generates power taking into account turbine and generator efficiencies for a given storage level and/or irrigation demands.

After discussion with CSIRO, the hydrological model used to estimate power generation was applied using the following key parameters and data inputs:

- No seepage
- Direct rainfall and evaporation on the reservoir
- No upstream demands
- All downstream demands were irrigation demands and were on-stream (i.e. not diverted)
- No environmental flow demands
- A daily model timestep
- Turbine hill curves as developed by Entura[6]
- Storage curves as provided
- FSL and dead storage levels as provided.
- Tailwater as calculated by Entura

3.8 Operating rules

The energy model applied the following operating rules to each turbine for all energy generating scenarios:

- No power generation occurs if the reservoir level is at or below the defined MOL
- Each turbine was specifically size for a range of inflow time exceedance percentiles for each catchment and the available head in the reservoir.
- For a given reservoir head the turbine operates at the most efficient range rather than the maximum discharge possible.
- For any site with two or more turbines the hydropower model does not optimise the discharge for each individual turbine. Each turbine was given equal priority for energy generation which distributes the discharge equally amongst the number of turbines. The range of turbine sizes

[6] Each hydro turbine has its own unique operating characteristics. The turbine hill curve produces the maximum and minimum heads and discharges that the turbine can operate without cavitation. Cavitation is detrimental to the turbine. For this level of study no energy is modelled when the head and flow available is within the selected turbines cavitation range.

considered provides an indicative range of energy generation for each potential dam site. Two quantitative definitions of annual energy generation were adopted:

- Firm Energy is the energy generated with 90% confidence in any given year.
- Secondary Energy is the energy able to be generated beyond the Firm Energy, and is assumed to be generated with at least 10% confidence and less than 90% confidence in any given year.

Two alternative energy generation scenarios were considered:

1. Power generation from “Irrigation” releases only; and
2. Hydropower generation only.

Under the first release scenario, energy is only generated using water released to meet downstream irrigation demands.

The second release scenario is to operate the reservoir as a hydropower scheme only. No attempt is made to address energy market demands under this scenario. The model simply generates energy according to operating rules reliant on storage levels and turbine characteristics[7].

[7] Turbine characteristics are defined by the hill curves developed in TURBNPRO including cavitation limits that in some instances prevent operation of the storage for power generation even if water is available. Further optimisation studies would allow further exploration of these issues.

Table 3-3 Turbine design scenarios

	DISCHARGE TIME EXCEEDANCE	RATED DISCHARGE[8] [m³/s]	NUMBER OF TURBINES [No.]	GROSS HEAD[9] [m]	NET HEAD (RATED)[10] [m]	INSTALLED CAPACITY [MW]
Mount Bennett	P10	47.90	2	17	11.1	4.42
	P30	8.90	2	17	13.4	0.99
	P50	1.90	1	17	14.9	0.24
	P70	0.23	1	17	14.4	0.03
Upper Adelaide	P10	16.13	1	20	19.0	2.55
	P30	2.97	1	20	19.6	0.49
	P50	0.79	1	20	19.4	0.13
	P70	0.17	1	20	17.8	0.03
Elizabeth	P10	6.45	1	34	31.7	1.70
	P30	0.77	1	34	33.0	0.21
	P50	0.18	1	34	33.3	0.05
	P70	0.10	1	34	33.9	0.03
Mitchell	P10	107.10	3	55	49.8	44.48
	P30	16.33	2	55	50.9	6.93
	P50	7.09	2	55	52.0	3.07
	P70	3.63	1	55	51.7	1.56
Walsh 03	P10	42.49	2	43	38.3	13.58
	P30	4.84	1	43	40.9	1.65
	P50	0.82	1	43	41.4	0.28
	P70	0.11	1	43	41.3	0.04
Walsh 04	P10	53.53	2	58	52.3	23.35
	P30	6.20	1	58	56.5	2.92
	P50	1.08	1	58	56.5	0.51
	P70	0.14	1	58	57.7	0.07

[8] The rated discharge of a turbine is the volume of water that the turbine will pass at the highest efficiency for a given net head.
[9] The gross head of a site is the maximum possible difference in elevation between the reservoir water level and the power house tailwater during operation
[10] The net head of a site is the head available for power generation which is estimated from the gross head less the head loss in the system.

4 Power generation

As described in Section 3.7, two broad energy generation scenarios were considered and a range of turbine design discharges were examined for energy generation.

Annual energy generation for each release scenario is tabulated in Table 4-1 and Table 4-2. In addition, the long term monthly firm and secondary energy generation are plotted in Appendix A . Here monthly boxplots of daily energy generation are used to demonstrate the seasonal variability of energy generation at each potential dam site for each design discharge value. Each boxplot shows the median daily energy generation in each month over the entire modelled time series. The box is defined by the first and third quartiles of the data. Whiskers extend to the maximum or minimum data point within 1.5 times the interquartile range. Values beyond the extent of the whiskers (i.e. outliers) are not shown on the plots for clarity. Key data for each box plot is tabulated in Appendix B .

4.1 Power generation from irrigation releases

Under this release scenario, discharges from the reservoir only occur when water is required downstream for irrigation purposes. A range of permutations and combinations of energy generating rules for the irrigation scenario were used for this desktop study. This included energy generation from irrigation releases only and energy generation from irrigation releases including spill events. Hydropower schemes would typically prefer the lowest tailwater elevation possible in order to maximise energy generation (i.e. maximum gross head). For this study a constant tailwater level was applied rather than a dynamic tailwater level based on reservoir discharges as detailed in section 3.3. Given the treatment of the site specific tailwater levels energy generation under reservoir spill periods are not included in this study as during reservoir spill periods power stations face the risk of inundation. As an observation it should be noted that the modelled power generation results for irrigation were quite insensitive to spill mainly due to large relative active storage volumes and infrequent spill (~1-2% variation in energy generation).

Table 4-1 presents the energy generation for each site at various rated discharges and the capacity factor for each rated discharge. Capacity factor is the ratio of energy that a power station produces to the energy that would be produced if it were operated at full capacity throughout an annual period. The capacity factor for each site is discussed further in Section 4.1.1.

From the tabulated results, the Mitchell site demonstrates the highest estimated annual power generation of around 104 GWh at a P10 discharge level. This site generates the majority of energy from secondary energy. The large portion of secondary energy is due to the significant active storage available (2,289 Mm^3). The region of the Mitchell site experiences highly seasonal inflows, with the large active storage available a large portion of energy is generated from stored water (secondary energy).

Table 4-1 Annual power generation – irrigation releases only (MWh)

DAM SITE	POWER	P10	P30	P50	P70
Mount Bennett	Firm	1,198	1,614	516	57
	Secondary	2,733	1,782	476	56
	Total	3,931	3,396	992	113
	Capacity Factor	10%	39%	48%	47%
Upper Adelaide	Firm	2,392	1,180	361	57
	Secondary	2,591	1,574	541	122
	Total	4,983	2,754	902	179
	Capacity Factor	22%	65%	81%	62%
Elizabeth	Firm	273	16	8	24
	Secondary	2,530	1,715	435	204
	Total	2,802	1,731	443	228
	Capacity Factor	19%	93%	94%	77%
Mitchell	Firm	16,400	9,021	2,605	1,901
	Secondary	88,502	47,816	21,917	10,460
	Total	104,902	56,837	24,523	12,361
	Capacity Factor	27%	94%	91%	90%
Walsh 03	Firm	6,700	3,760	464	57
	Secondary	21,068	10,381	1,650	203
	Total	27,768	14,141	2,114	260
	Capacity Factor	23%	98%	85%	78%
Walsh 04	Firm	22,092	10,693	1,784	151
	Secondary	26,243	13,201	2,404	217
	Total	48,336	23,894	4,187	368
	Capacity Factor	24%	93%	94%	62%

4.1.1 DISCUSSION

In order to compare the power generation of different hydropower sites over a number of rated discharges the absolute energy generated should be read in conjunction with the site's energy capacity factor. A site capacity factor is the ratio of energy that a power station produces to the energy that would be produced if it were operated at full capacity over a year. A higher installed capacity that makes use of infrequent high discharges will produce more energy, but the consistency of energy generation throughout a year is lower.

A financial analysis is required to select the most optimum sizing of the power station for each site.

Energy generation from the Mt Bennett dam site demonstrates the high seasonality of inflows to and outflows from the storage. Very low to zero power generation is available from August to January. For lowest installed capacity (P70), relatively consistent power generation is possible between March and June, but power generation in February and July is highly variable. More consistent and higher power generation is possible using a higher installed capacity relating to the P50 flow from February to July. Larger units provide an interplay between storage and releases that reduces the reliability of power generation.

At the Upper Adelaide potential dam site, a similar pattern of energy generation is observed. Relatively unreliable energy generation in the period September to December for P70, P50 and P30 sized stations. For P10 operations decreased availability is experienced in October to December; this is in part driven by the large size of the turbines in that case which are not able to take advantage of the low head and flow periods.

For the potential dam sites in the Mitchell catchment the Walsh 04 dam site provides the largest firm energy component at P10 (23 MW). As demonstrated by the box plot the large active storage at this site allows for a median energy generation to be generated each month. The high median energy generation for the P30, 50 and 70 is due to the large active storage available (2289 Mm^3). This storage provides water availability to meet irrigation demands outside of the P10 demand scenario. Notably the most variable power generation occurs during the months of October to January.

Power generation from the Elizabeth Creek potential dam site has similar seasonal characteristics to the Mitchell site. Power generation is least reliable in the October to January period with greater variability in median monthly power production driven by larger turbine sizes.

Power generation from the Walsh 04 dam site is relatively consistent throughout the year for most turbine discharges. However, the wide whiskers on the boxplot indicate large extremes do occur.

Power generation from the Walsh 04 dam site is highly variable apart from the period February to August reflecting the much lower storage capacity of this site compared with Walsh 03.

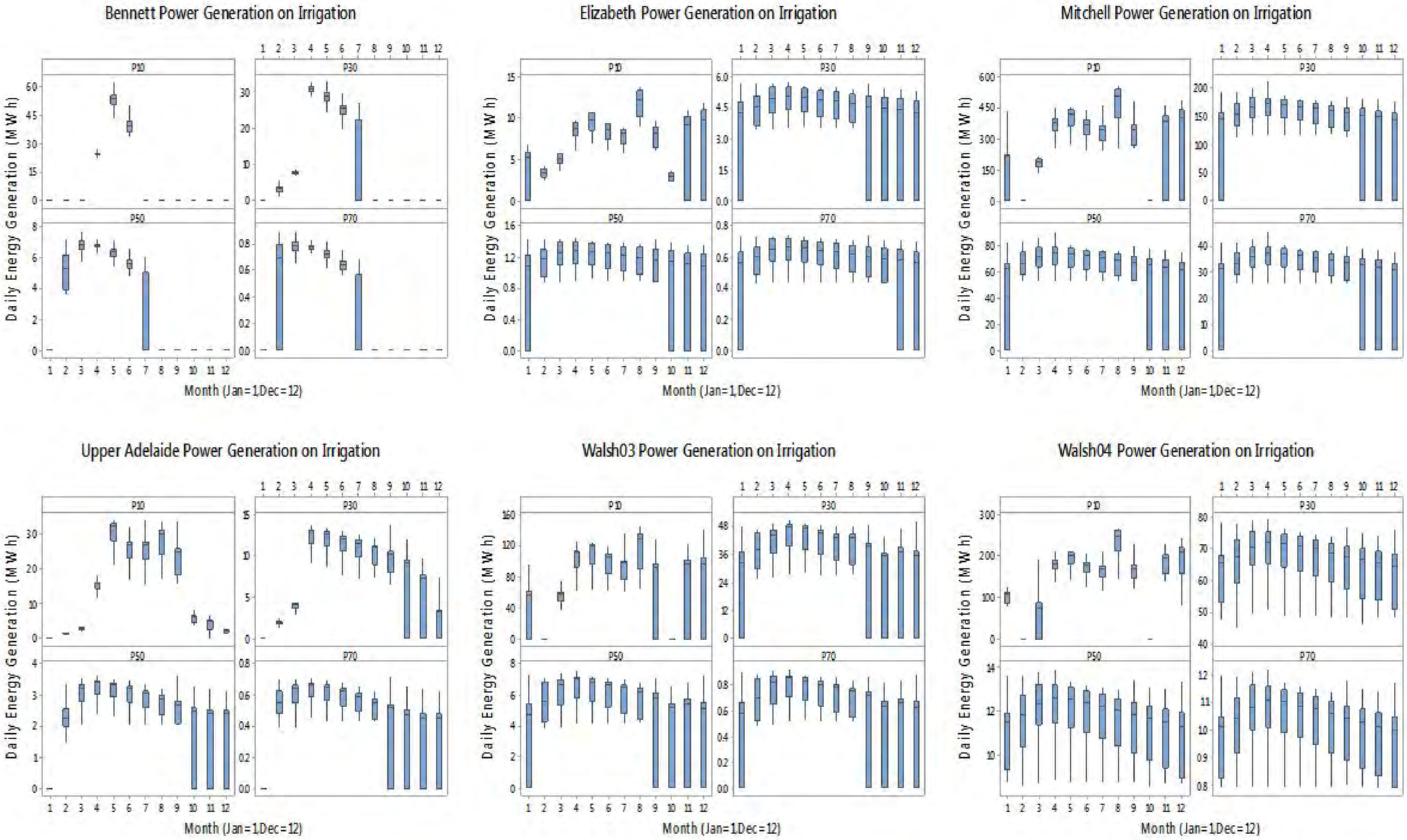


Figure 4-1 Box plots of power generation from irrigation releases

4.2 Power generation only

Under this release scenario, the most efficient discharge through each turbine for a given head was typically found to produce the maximum total annual energy production. No attempt was made to match the energy generation to any estimated market energy demands. The models simply generated energy according to rules based on storage levels and turbine characteristics (see section 3.8).

Table 4-2 Average annual power generation - hydropower only (MWh)

DAM SITE	POWER	P10	P30	P50	P70
Mount Bennett	Firm	4,508	6,448	1,759	210
	Secondary	10,099	1,127	55	5
	Total	14,607	7,576	1,814	215
	Capacity Factor	38%	87%	88%	89%
Upper Adelaide	Firm	1,702	3,622	1,014	202
	Secondary	10,996	401	28	3
	Total	12,698	4,023	1,042	206
	Capacity Factor	57%	94%	93%	71%
Elizabeth	Firm	618	1,456	405	203
	Secondary	9,249	134	8	13
	Total	9,867	1,589	413	215
	Capacity Factor	66%	86%	87%	72%
Mitchell	Firm	24,496	49,067	22,487	11,522
	Secondary	233,431	2,943	398	160
	Total	257,926	52,010	22,886	11,682
	Capacity Factor	66%	86%	85%	85%
Walsh 03	Firm	7,122	11,640	2,059	264
	Secondary	49,647	606	26	5
	Total	56,768	12,246	2,085	269
	Capacity Factor	48%	85%	84%	81%
Walsh 04	Firm	14,417	20,634	3,833	337
	Secondary	133,430	1,151	52	13
	Total	147,847	21,785	3,885	350
	Capacity Factor	72%	85%	87%	59%

4.2.1 DISCUSSION

For the power only release scenario the energy generated was based on water availability, taking into consideration the most efficient energy production for a given head and flow for each individual turbine.

All of the potential dam sites have significant active storages. These large storages provide water availability for energy generation when reservoir inflow volumes are low. This is clearly represented in the boxplots which show that even at low inflow probability (P70) power generation does not reduce significantly. The Mitchell site once again demonstrates the largest energy potential as it has a significant gross head available (55 m) and a significant storage (2,289 Mm^3) which enables power generation during the dry season.

Most P10 estimates of energy generation are considered under-estimates due to the need to avoid turbines cavitation under high flows. These energy estimates are often less than the P70 flow condition for this reason. Further optimisation of turbine configurations outside the scope of the present study is required to confirm the P10 estimates.

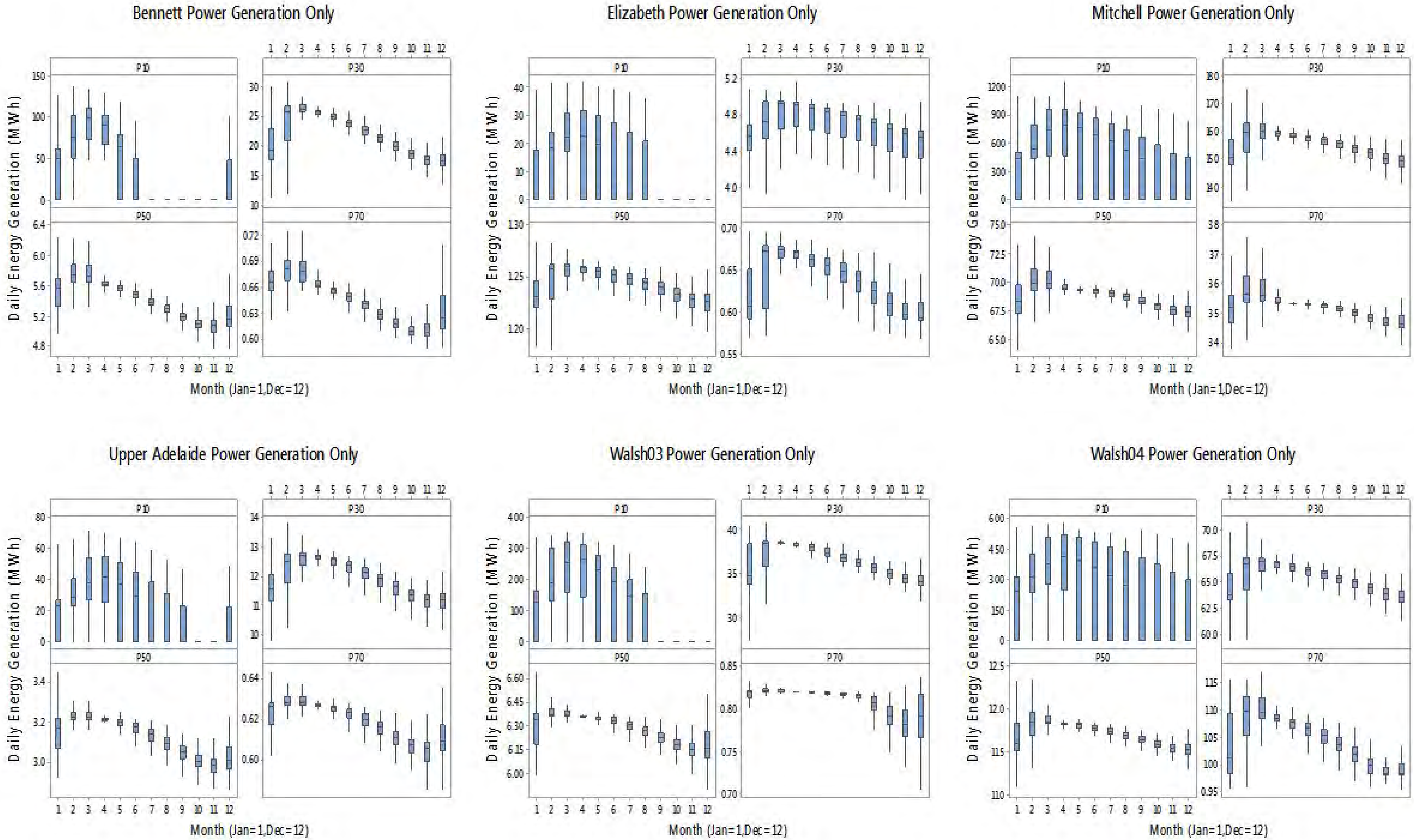


Figure 4-2 Box plots of power generation only

4.3 Project grid connection points

In this study the short-listed dam sites located in the Mitchell catchment are within a reasonable distance to establish a new connection to the National Electricity Market (NEM). The NEM is the interconnected power system across South Australia, New South Wales, Victoria and Queensland. It was also assumed that the two dams located in the Darwin catchments would be connected to the NT distribution network.

The Australian Energy Market Operator (AEMO) is responsible for operating the electricity market of the eastern seaboard states and Western Australia. The NT Power and Water Corporation is responsible for the operation of the NT grid.

Entura have identified potential grid connection points based on the installed capacity and the most appropriate voltage level. No investigation of the connection point spare capacity was undertaken, only the technical capability to connect each potential dam sites power plant. In addition no investigation of the transmission line route has been undertaken, only the theoretical straight line distance between the proposed development and the potential connection point.

4.3.1 MOUNT BENNETT

Mount Bennett is located approximately 50 km SW of Darwin. The nearest connection point is a 22 kV connection point in Collet Creek located approximately 34 km away. Any proposed new transmission line would have to acquire an easement which would pass through significant number of existing agricultural lands. An alternative 66 kV connection would require a new transmission line approximately 50 km long.

4.3.2 UPPER ADELAIDE

Upper Adelaide is located approximately 90 km South of Darwin. The nearest connection point is a 22 kV connection point at the town of Adelaide River approximately 3.5 km away. The transmission line and power station should be located on the left bank of the river as the town is located on same side. This arrangement would avoid major costs associated with a transmission line river crossing. An alternative 66 kV connection would require a new transmission line approximately 95 km long.

4.3.3 MITCHELL

The Mitchell potential dam site is located in far north Queensland on the fringe of the NEM. The nearest connection point is a 66 kV transmission line which travels along the Mulligan highway. From Entura's investigations the transmission line is approximately 55 km away from the Mitchell River potential dam site. Connection infrastructure would need to be built in order to allow the new generation to 'cut-in' to the existing 66 kV line. This would include an appropriately size zone or terminal substation that would step up the transmission line voltage to interconnect with the NEM network.

4.3.4 ELIZABETH

The Elizabeth Creek development has two potential connection points. One option is to connect to the same 66 kV connection point along the Mulligan Highway as the Mitchell River potential dam site. An alternative connection point is the existing 66/22 kV sub-station located approximately 65 km SE from the dam near the town of Chillagoe. The sub-station connection is preferred provided sufficient capacity is available as there would be no further infrastructure costs for connection.

4.3.5 WALSH 03 AND 04

Both Walsh 03 and Walsh 04 developments would be connected to the existing 66/22 kV sub-station in Chillagoe. For Walsh 03 a 25 km, 22 kV transmission line would be appropriate. For Walsh 04 a 66 kV transmission line approximately 28 km long would suffice.

4.4 Electrical balance of plant – CAPEX

For each of the installed capacities Entura have estimated the capital expenditure (CAPEX) required for the development of the power station and connection to the nearest point on the existing electricity grid (Table 4-3). In Queensland connections are assumed to be to the NEM. In the Northern Territory it is likely that a separate 66 kV transmission line may also be required in addition to the costs shown in the table.

The indicative capital cost for the development of the powerhouse only has been estimated by taking into consideration the dam arrangement as proposed by CSIRO and estimating the costs associated with adding a penstock and power station to an existing dam arrangement

The Electrical Balance of Plant is considered to be the electrical assets that carry power from the turbine generators to the electricity grid. For simplicity all electrical assets located outside of the powerhouse are termed the Balance of Plant including the transmission line to interconnect to the existing grid. No allowance has been made for the costs associated with acquiring easements, native vegetation offsets, grid connection charges or contingencies.

Table 4-3 Indicative project CAPEX

DAM SITE	DISCHARGE TIME EXCEEDANCE	INSTALLED CAPACITY [MW]	POWER STATION [$AUD Million]	ELECTRICAL BALANCE OF PLANT [$AUD Million]	TOTAL PROJECT COST [$AUD Million]	TOTAL PROJECT COST PER MW [$AUD Million/MW]
Mount Bennett	P10	4.42	14.08	9.10*	23.18	5.2
	P30	1.0	4.13	2.04	6.17	6.2
	P50	0.24	0.76	0.49	1.25	5.3
	P70	0.03	0.08	0.06	0.14	5.0
Upper Adelaide	P10	2.55	8.61	4.53*	13.14	5.2
	P30	0.49	1.31	0.87	2.18	4.5
	P50	0.13	0.25	0.23	0.48	3.8
	P70	0.03	0.07	0.05	0.12	4.8
Elizabeth	P10	1.70	5.43	13.35	18.78	11.0
	P30	0.21	0.58	1.65	2.23	10.5
	P50	0.05	0.11	0.39	0.50	9.7
	P70	0.03	0.06	0.24	0.30	10.6
Mitchell	P10	44.48	109.43	22.50	131.93	3.0
	P30	6.93	15.26	3.51	18.76	2.7
	P50	3.07	12.23	1.55	13.79	4.5
	P70	1.56	4.50	0.79	5.29	3.4
Walsh 03	P10	13.58	43.95	13.75	57.70	4.2
	P30	1.65	4.99	1.67	6.66	4.0
	P50	0.28	0.70	0.28	0.98	3.5
	P70	0.04	0.08	0.04	0.12	3.1
Walsh 04	P10	23.35	63.67	14.00	77.67	3.3
	P30	2.92	7.41	1.75	9.16	3.1
	P50	0.51	1.05	0.31	1.36	2.7
	P70	0.07	0.12	0.04	0.16	5.2

If, due to capacity constraints, it is necessary to install separate new transmission lines in the Northern Territory the estimated Balance of Plant costs for P10 power developments would be:

- Mount Bennett $14.0 million
- Upper Adelaide $23.0 million

Further investigation of the Northern Territory transmission networks and spare capacity is warranted.

5 Summary and conclusion

This study is a desktop analysis. No scheme optimisation was undertaken and it is assumed that power can be connected to the nearest connection point in the existing transmission network. The table below summaries the energy generation for each discharge probability at each of the six potential dam sites. For each discharge probability the installed capacity was determined by the inflow duration curve which was developed from the full record of modelled inflows. For each discharge probability where the inflow duration curve is proportionally similar to the downstream demand (irrigation) duration curve the energy between a hydropower scenario and irrigation scenario are similar. Where the inflow is significantly larger than irrigation demand the hydropower scenario achieves a greater energy yield than the irrigation scenario.

Table 5-1 Summary of dam sites energy generation
CAPEX and OPEX are in 2017 Australian dollars.

DAM SITE	PARAMETER	UNIT	P10	P30	P50	P70
Mt Bennett	Rated Discharge	[m³/sec]	47.9	8.9	1.9	0.23
	Installed Capacity	[MW]	4.4	1	0.2	0.03
	Hydro Power	[MWh]	14,607	7,576	1,814	216
	Irrigation	[MWh]	3,931	3,396	992	113
	CAPEX	[$million]	$23	$6	$1.25	$0.14
	OPEX	[$/Year]	$695,395	$185,102	$37,482	$4,111
Upper Adelaide	Rated Discharge	[m³/sec]	16.13	2.97	0.79	0.17
	Installed Capacity	[MW]	2.5	0.5	0.1	0.03
	Hydro Power	[MWh]	12,698	4,023	1,042	206
	Irrigation	[MWh]	4,983	2,754	902	179
	CAPEX	[$million]	$13	$2.18	$0.48	$0.12
	OPEX	[$/Year]	$394,108	$65,534	$14,548	$3,616
Mitchell	Rated Discharge	[m³/sec]	107.1	16.33	7.09	3.63
	Installed Capacity	[MW]	44.48	6.93	3.07	1.56
	Hydro Power	[MWh]	257,926	52,010	22,886	11,682
	Irrigation	[MWh]	104,902	56,837	24,523	12,361
	CAPEX	[$million]	$132	$19	$13.80	$5.30
	OPEX	[$/Year]	$3,957,812	$562,819	$413,596	$158,588
Elizabeth	Rated Discharge	[m³/sec]	6.45	0.77	0.18	0.10
	Installed Capacity	[MW]	1.7	0.21	0.05	0.03
	Hydro Power	[MWh]	9,867	1,589	413	215
	Irrigation	[MWh]	2,802	1,731	443	228
	CAPEX	[$million]	$19	$2.23	$0.50	$0.30
	OPEX	[$/Year]	$563,451	$66,968	$14,936	$9,009

DAM SITE	PARAMETER	UNIT	P10	P30	P50	P70
Walsh 03	Rated Discharge	[m³/sec]	42.49	4.84	0.82	0.11
	Installed Capacity	[MW]	13.58	1.65	0.28	0.04
	Hydro Power	[MWh]	56,768	12,246	2,085	270
	Irrigation	[MWh]	27,768	14,141	2,114	260
	CAPEX	[$million]	$58	$7	$0.98	$0.12
			$1,730,927	$199,933	$29,453	$3,548
Walsh 04	Rated Discharge	[m³/sec]	53.53	6.20	1.08	0.14
	Installed Capacity	[MW]	23.35	2.92	0.51	0.07
	Hydro Power	[MWh]	147,848	21,785	3,884	350
	Irrigation	[MWh]	48,336	23,894	4,187	368
	CAPEX	[$million]	$78	$9	$1.36	$0.16
	OPEX	[$/Year]	$2,330,086	$274,702	$40,663	$4,734

From the hydropower assessment of the irrigation scenario the P10 design discharge consistently produces more energy for all sites over the other three design discharges (refer to Figure 5-1). This is due to the larger turbine selection being able to pass a larger volume of the total irrigation release. All volumes of water which are greater than the maximum capacity of the turbine for any given head elevation has been assumed as to be passed via bypass pipework as irrigation discharges downstream of the power station.

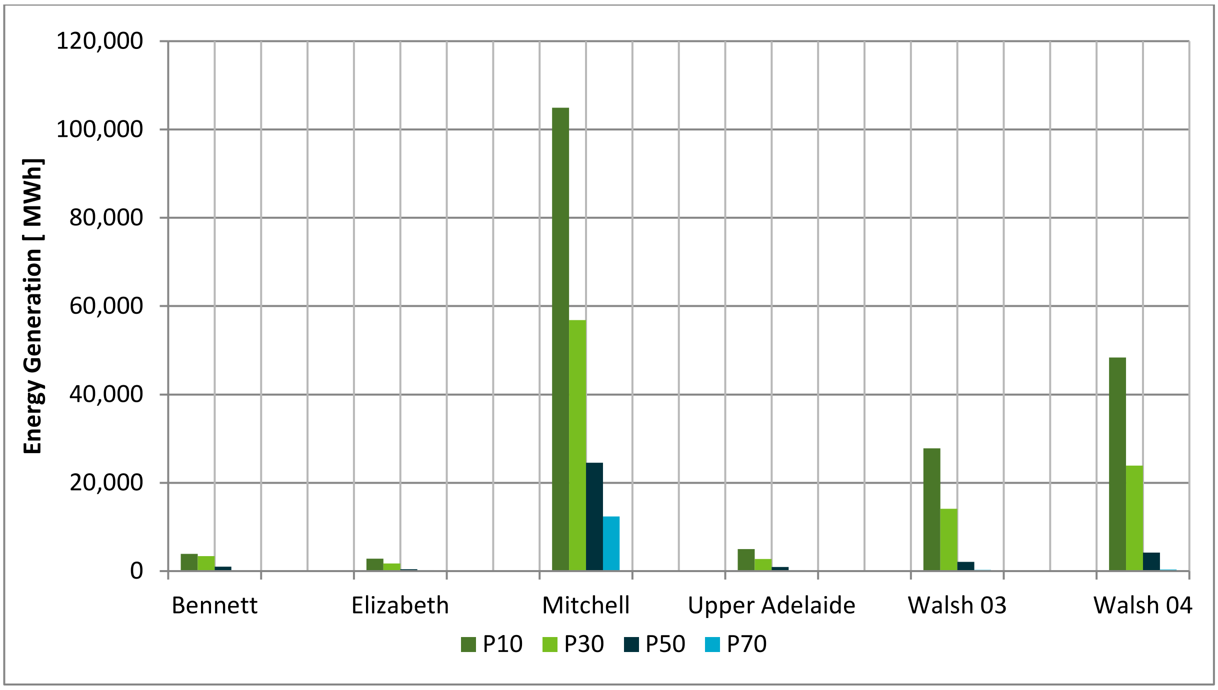


Figure 5-1 Power generation summary irrigation

Energy generation across the hydropower only scenario depicts a similar trend were the P10 design discharge produces the most energy (refer to Figure 5-2). The Mitchell, Walsh 03 and Walsh 4 have a large differential between the P10 and P30 which reflect large infrequent inflows to the reservoirs. The Bennett, Elizabeth and Upper Adelaide show less variation of inflows from P10 to P30.

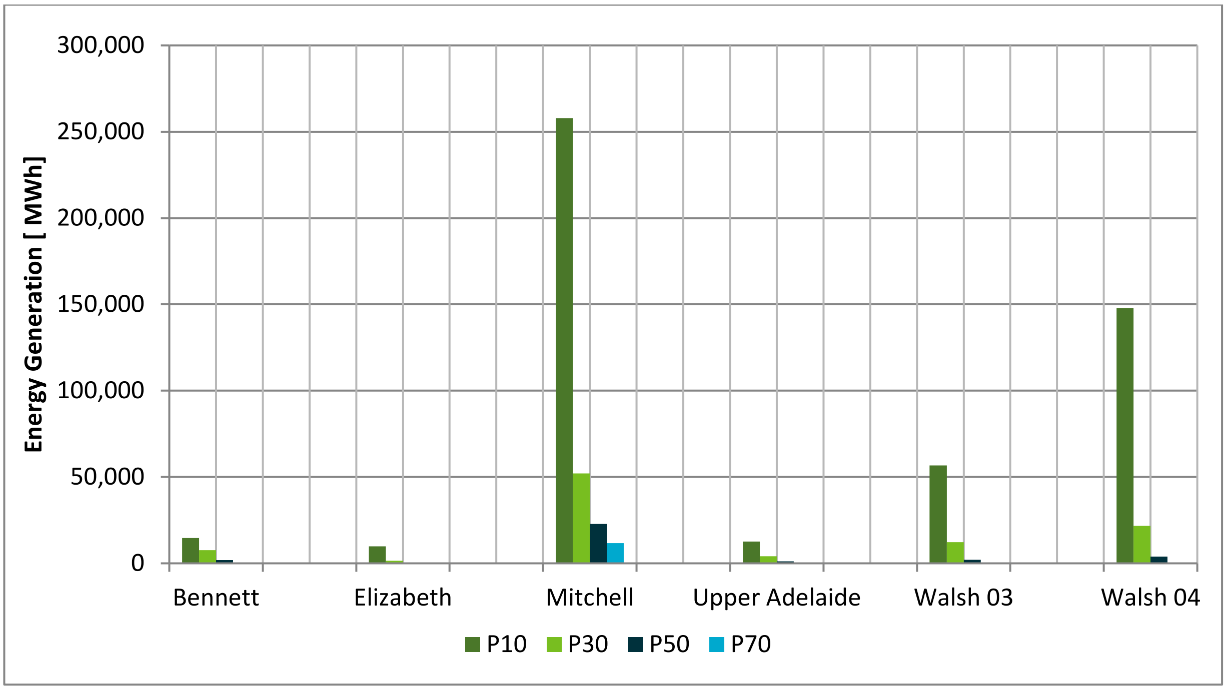


Figure 5-2 Power generation summary (hydropower only)

6 References

International Hydropower Association (IHA) (2016) Hydropower Status Report 2016. Researched and edited by the team at IHA central office.

Petheram C, Rogers L, Read A, Gallant J, Moon A, Yang A, Gonzalez D, Seo L, Marvanek S, Hughes J, Ponce Reyes R, Wilson P, Wang B, Ticehurst C and Barber M (2017) Assessment of surface water storage options in the Fitzroy, Darwin and Mitchell catchments. A technical report to the Australian Government from the CSIRO Northern Australia Water Resource Assessment, part of the National Water Infrastructure Development Fund: Water Resource Assessments. CSIRO, Australia.

Key datasets

- Catchment boundary files – GIS shapefiles and Google Earth kmz files of the catchment area for each site.
- Demand Patterns – Monthly downstream demand pattern (as a proportion of 1) required for agricultural purposes as defined by CSIRO.
- Full Supply Level Inundation Extents – GIS shapefiles and Google Earth kmz files showing the inundation extent at the selected full supply level (FSL) for each of the 6 sites.
- Gauging station locations and rating curves – Rating tables for gauging stations immediately downstream of or close to each of the 6 sites.
- HSaV files – Technical details for each dam location covering
  - Reservoir height (m)
  - Surface area (m^2)
  - Volume (m^3) relationship for each of the 6 sites.
- Output of behaviour analysis model – Outputs from the behaviour analysis model at each site for the selected FSL at about 85% annual time reliability.
- Reports and conventions – this folder contains the Word template and language, map and chart conventions.
- Runoff and climate files – Daily catchment average runoff, rainfall and evaporation data at the reservoir.
- Spillway rating curves – Spillway ratings for each of the 6 sites.

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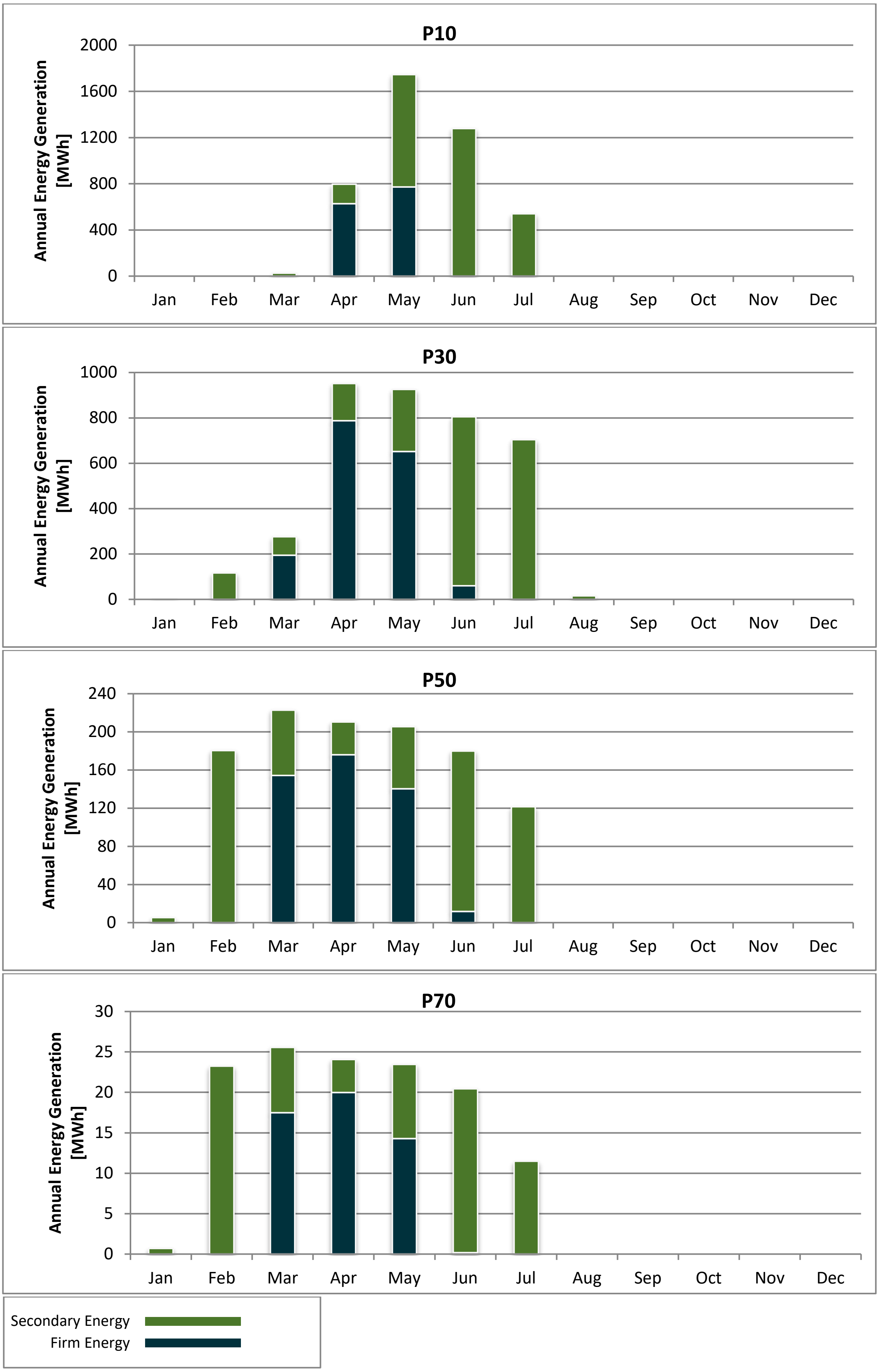
Part II Appendices

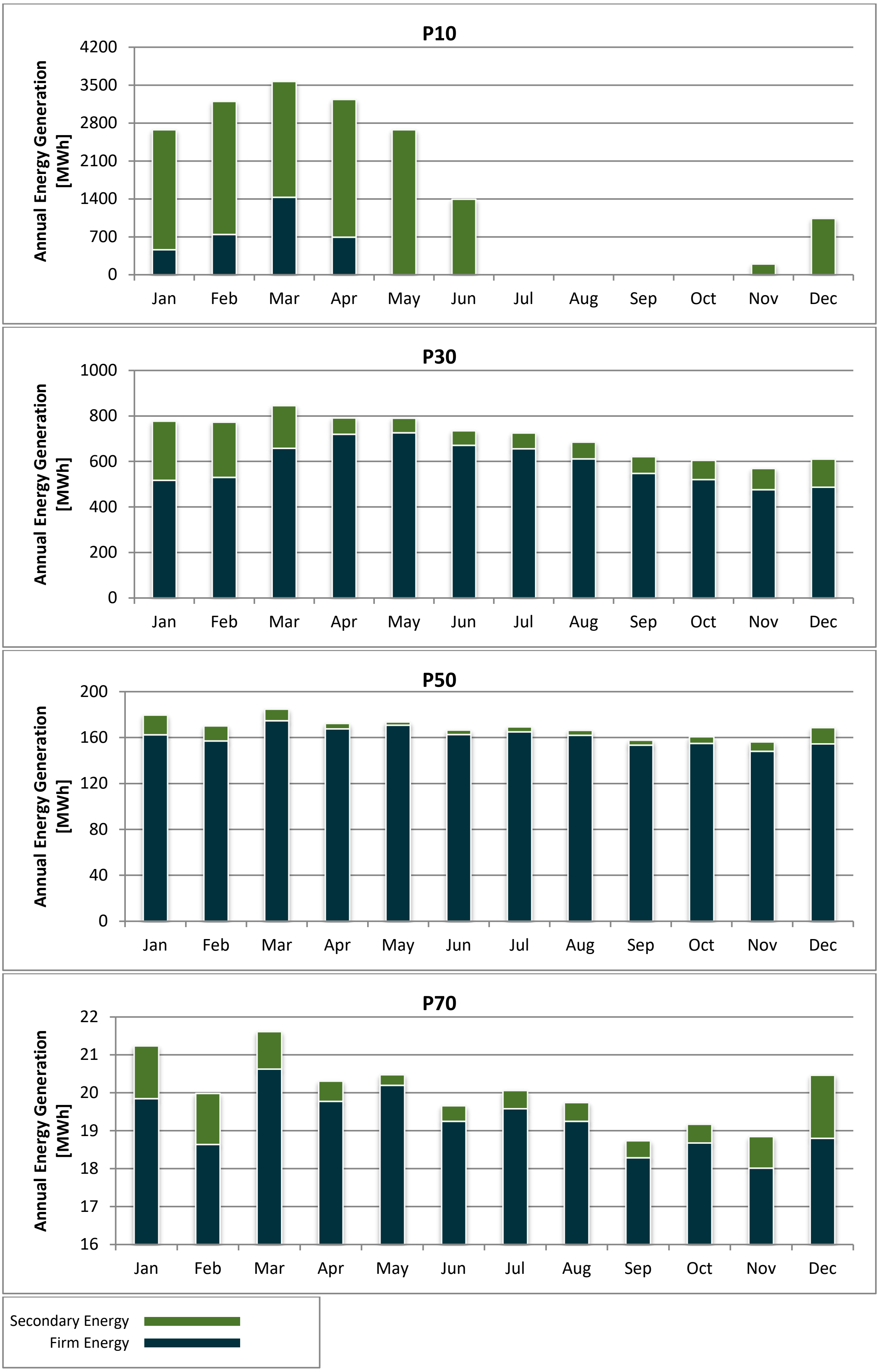
Appendix A Monthly energy generation

A.1 Mount Bennett – annual energy generation - irrigation



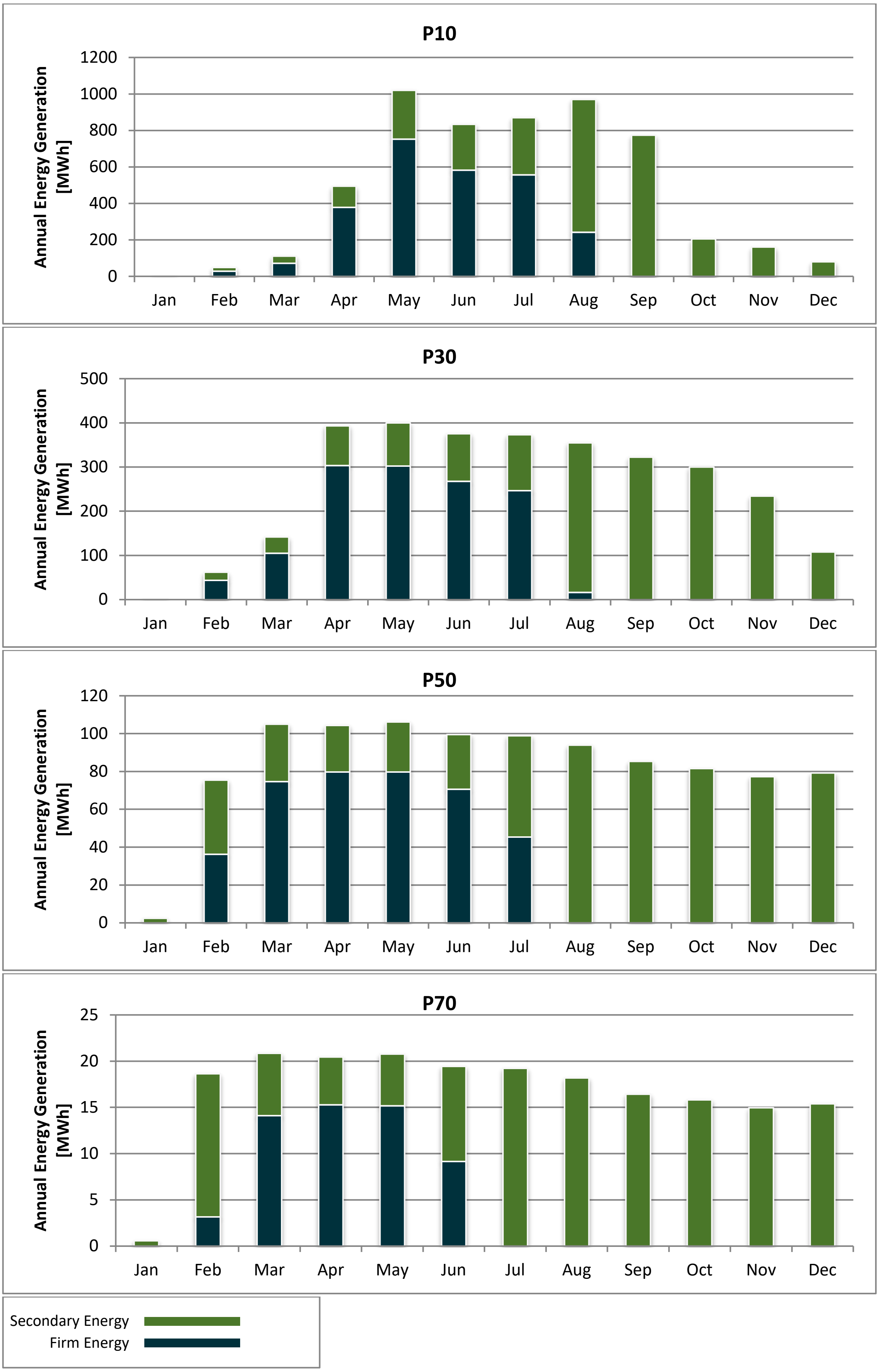
Apx Figure A-1 Mount Bennett – annual energy generation - irrigation

A.2 Mount Bennett – hydropower only energy generation



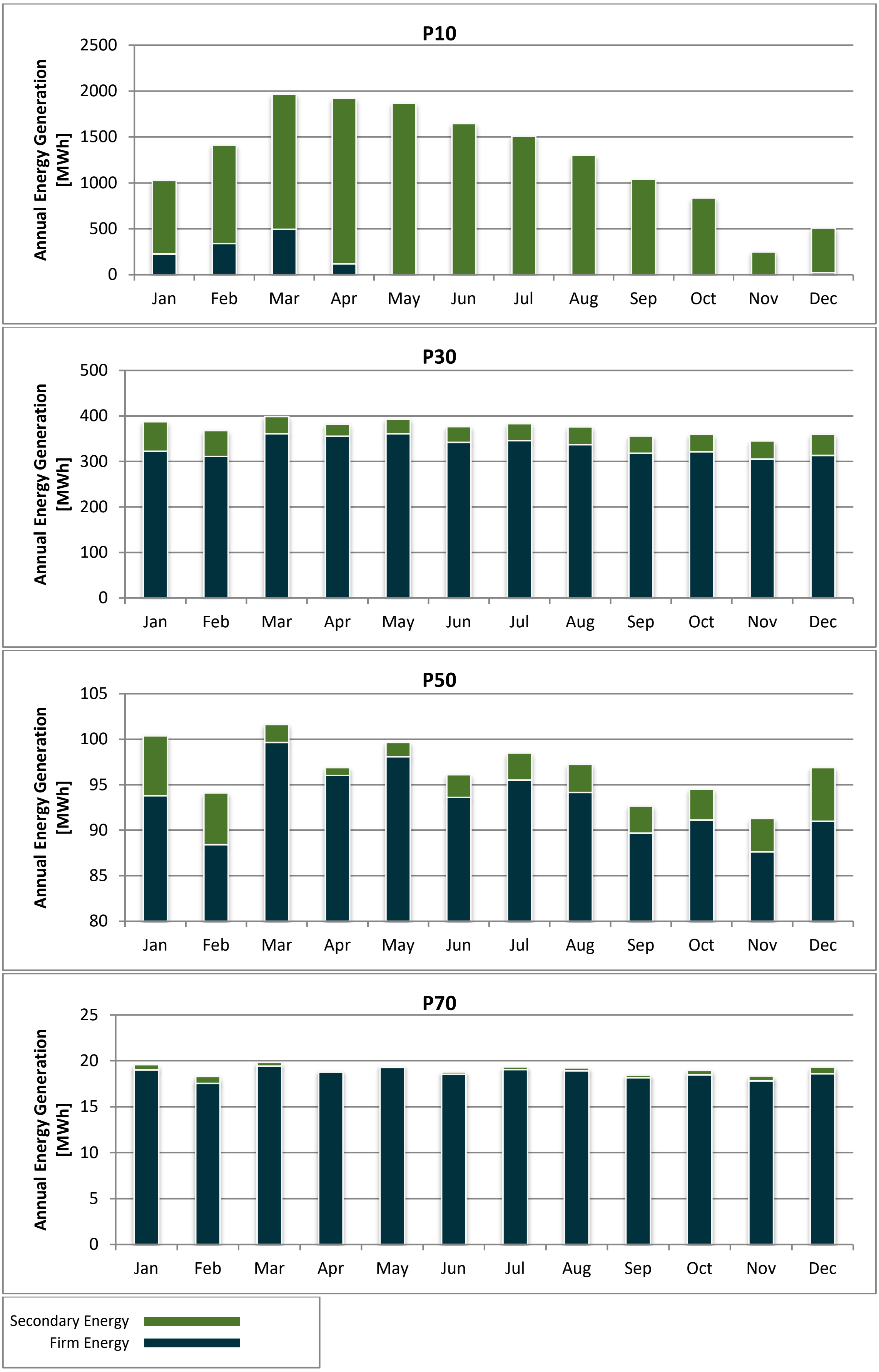
Apx Figure A-2 Mount Bennett – hydropower only energy generation

A.3 Upper Adelaide – irrigation only energy generation



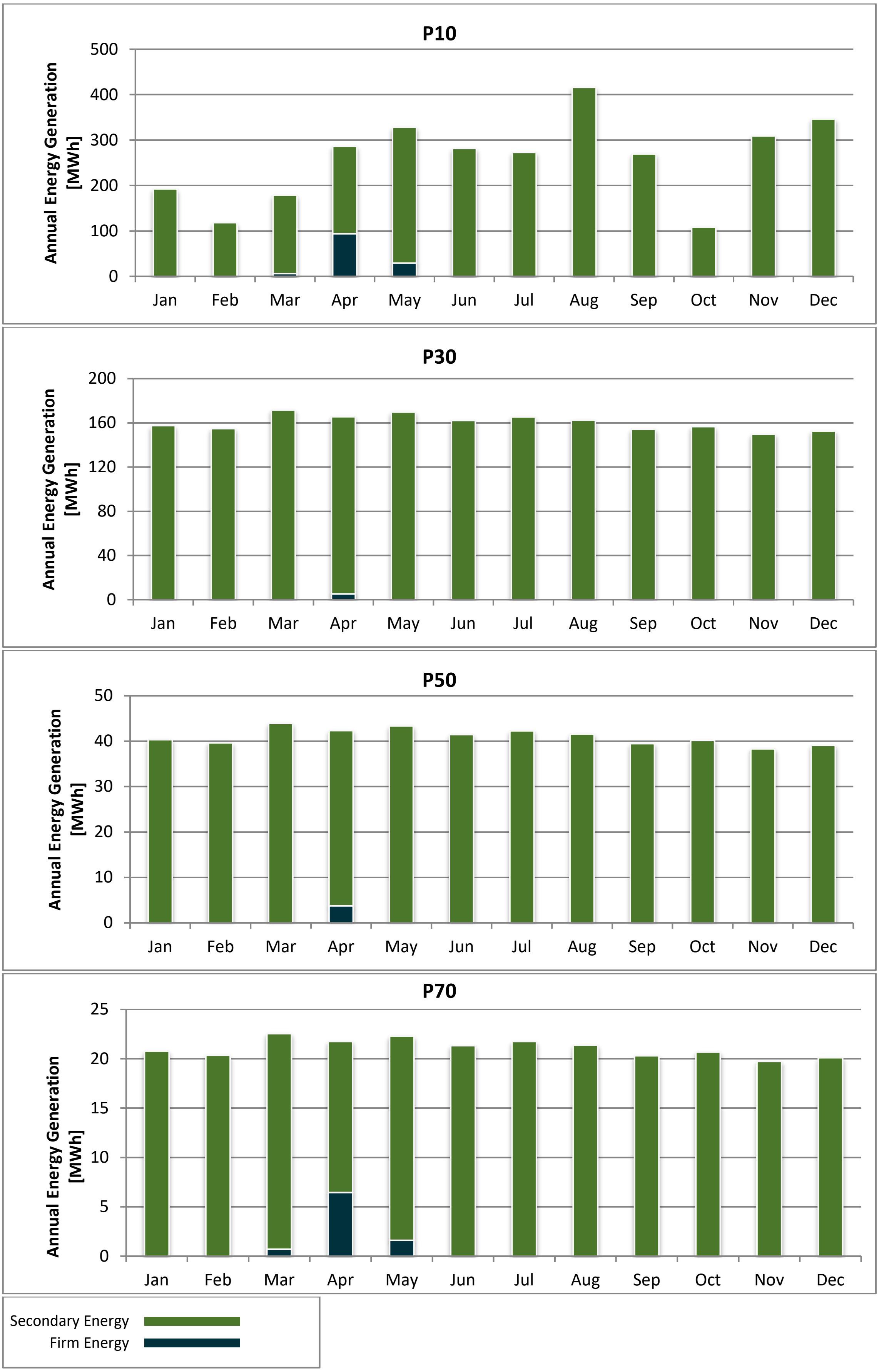
Apx Figure A-3 Upper Adelaide – irrigation only energy generation

A.4 Upper Adelaide – hydropower only energy generation



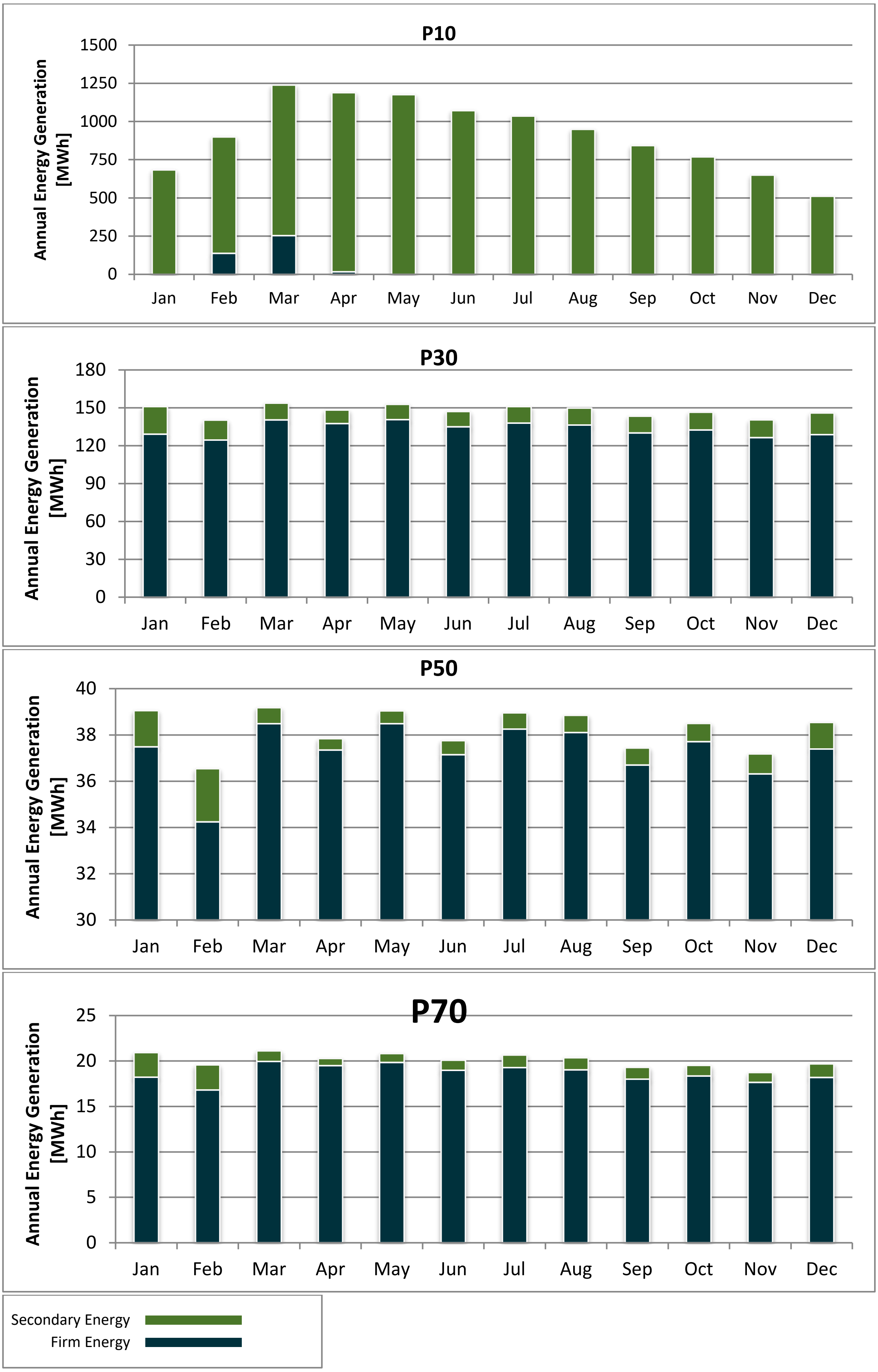
Apx Figure A-4 Upper Adelaide – hydropower only energy generation

A.5 Elizabeth - irrigation only energy generation



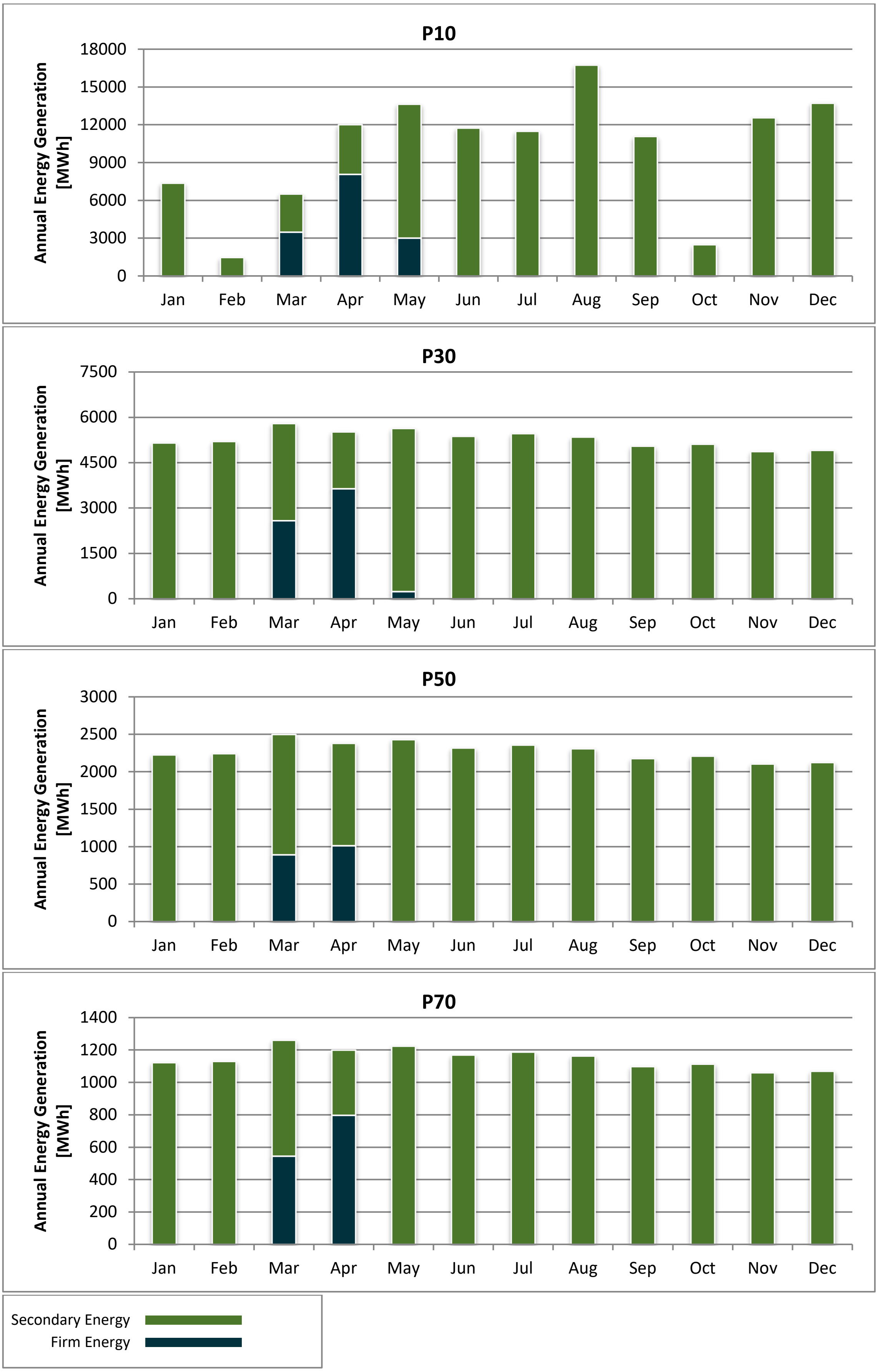
Apx Figure A-5 Elizabeth - irrigation only energy generation

A.6 Elizabeth01 - hydropower only energy generation



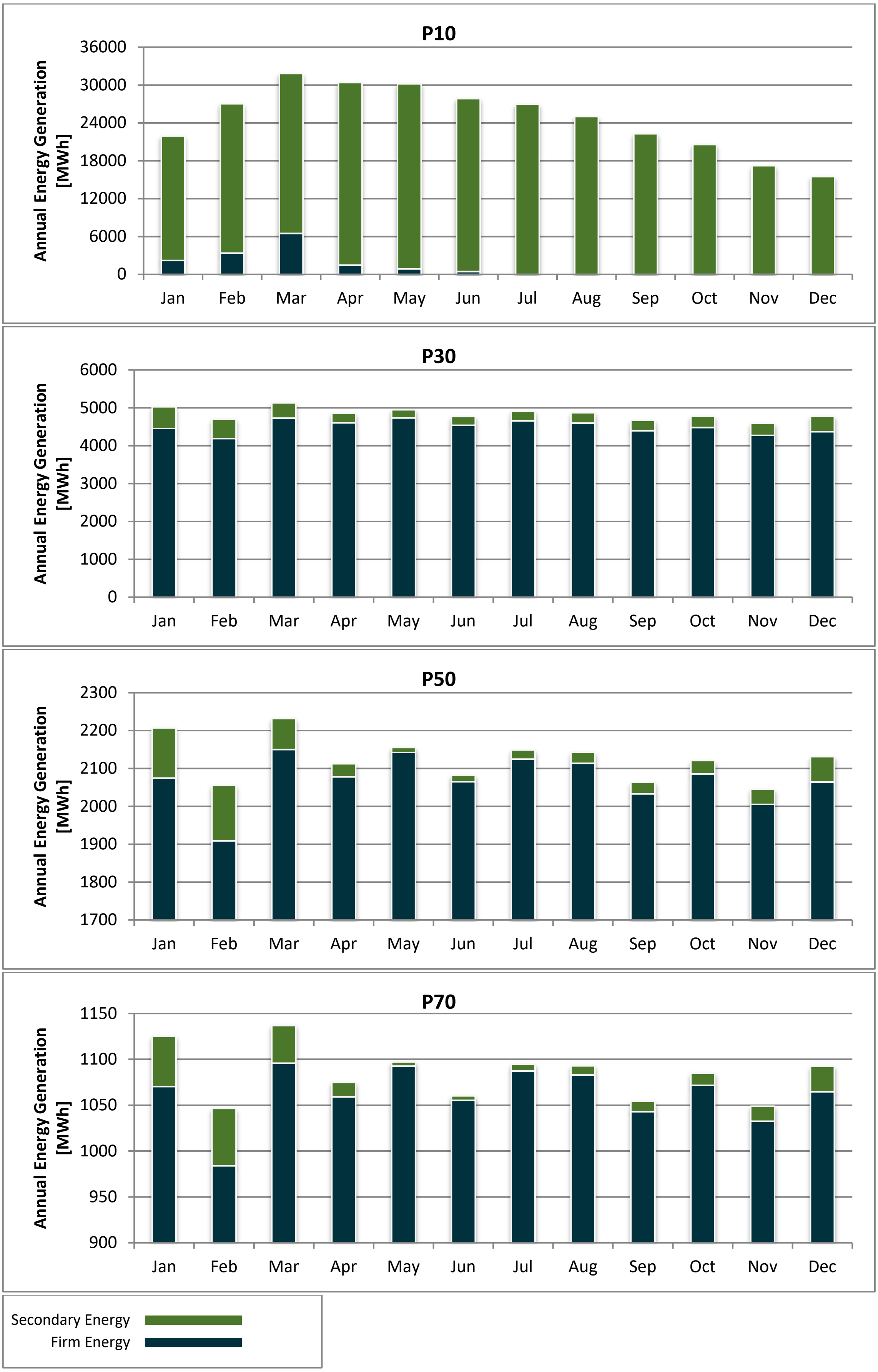
Apx Figure A-6 Elizabeth01 - hydropower only energy generation

A.7 Mitchell – irrigation only energy generation



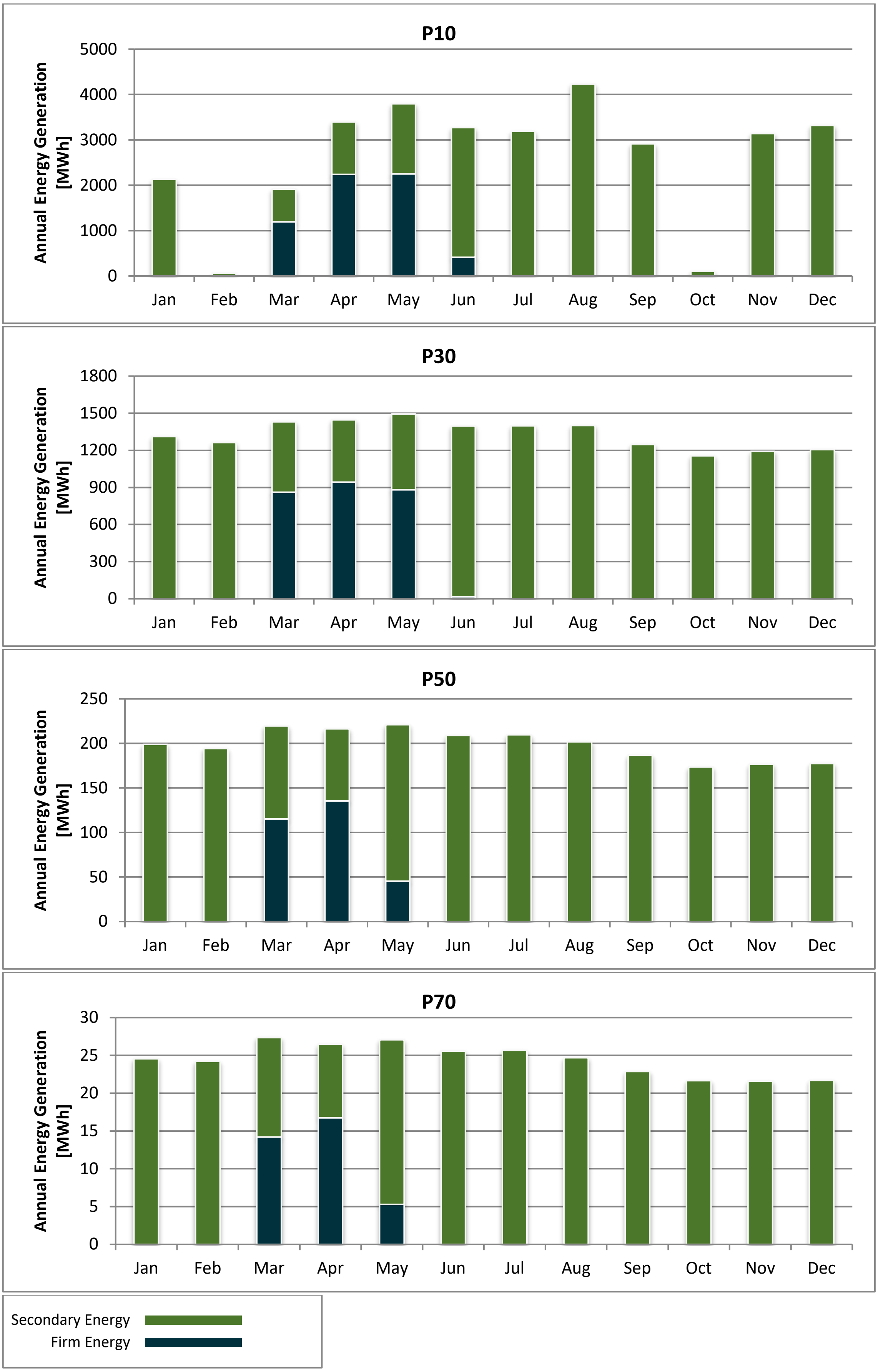
Apx Figure A-7 Mitchell – irrigation only energy generation

A.8 Mitchell – hydropower only energy generation



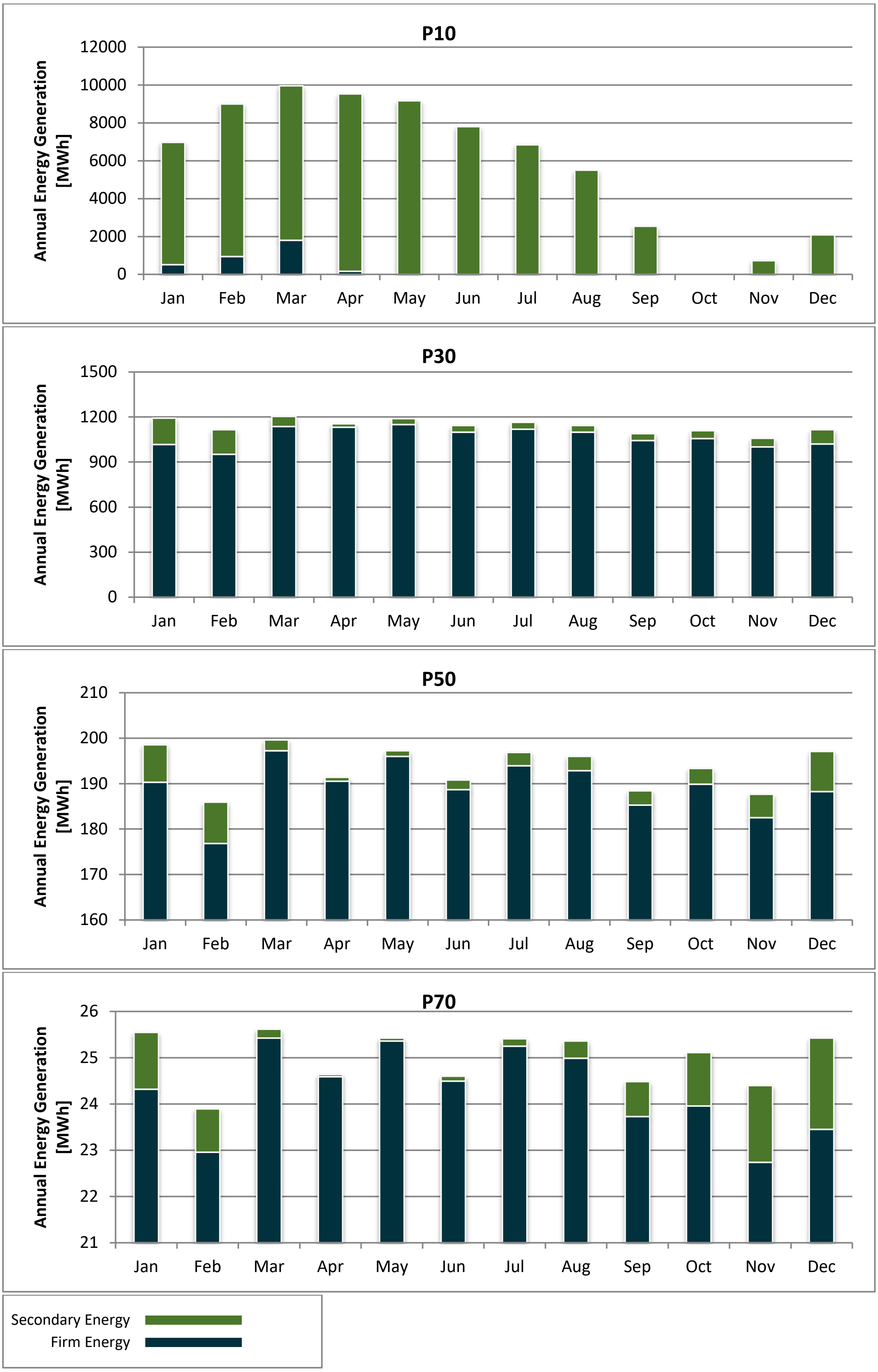
Apx Figure A-8 Mitchell – hydropower only energy generation

A.9 Walsh3 – irrigation only energy generation



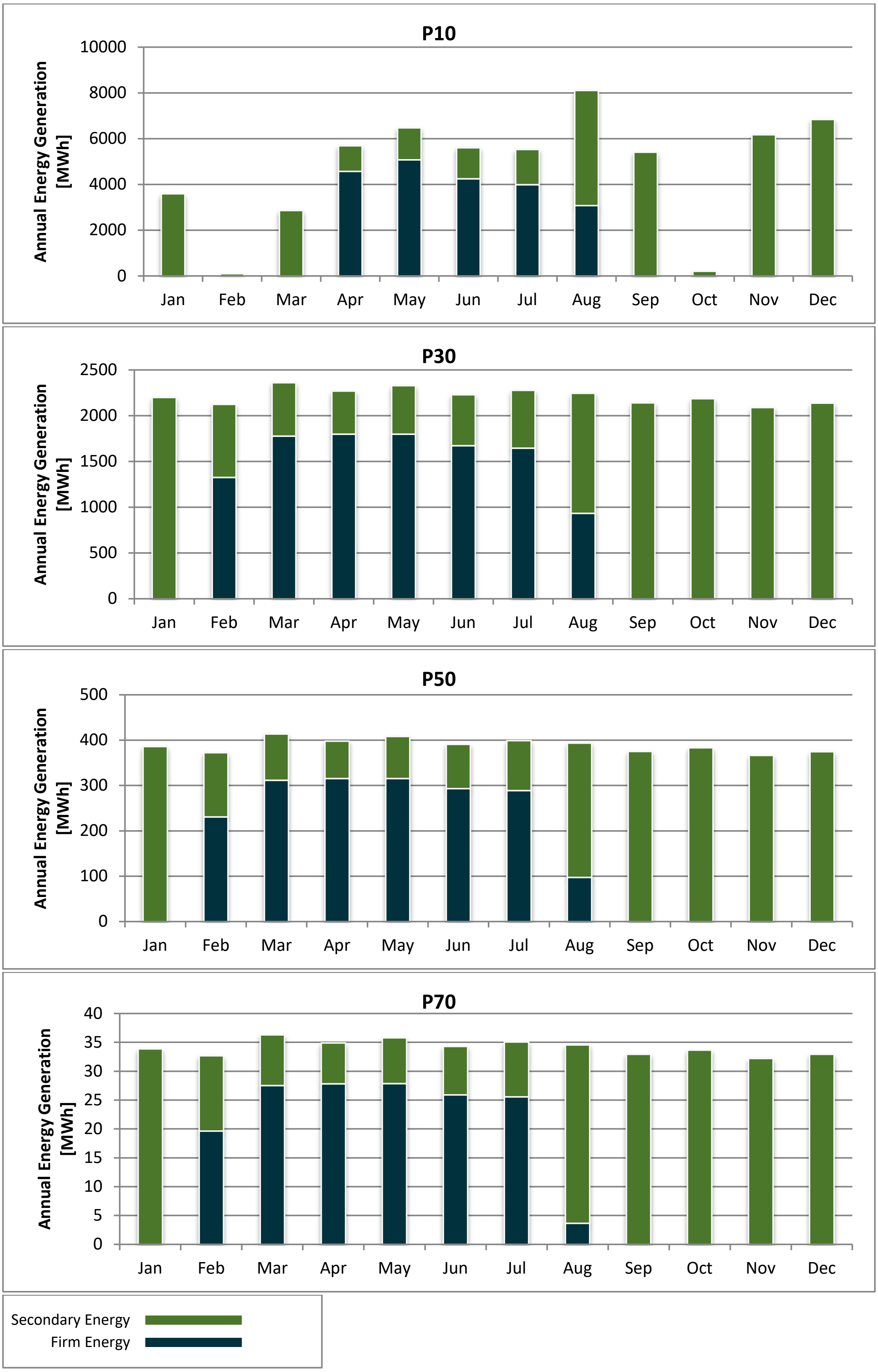
Apx Figure A-9 Walsh3 – irrigation only energy generation

A.10 Walsh 03 – hydropower only energy generation



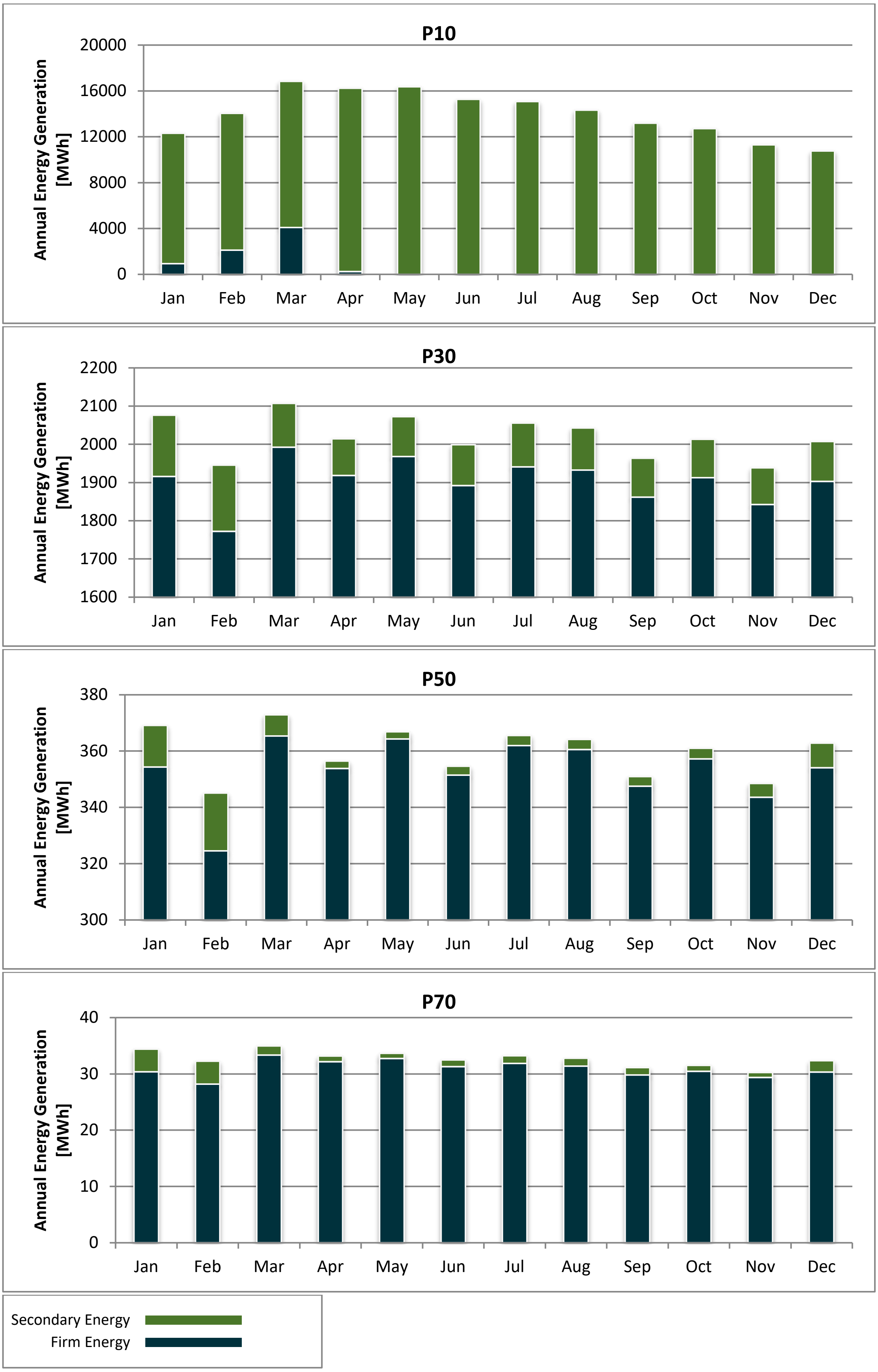
Apx Figure A-10 Walsh 03 – hydropower only energy generation

A.11 Walsh 04 – irrigation only energy generation



Apx Figure A-11 Walsh 04 – irrigation only energy generation

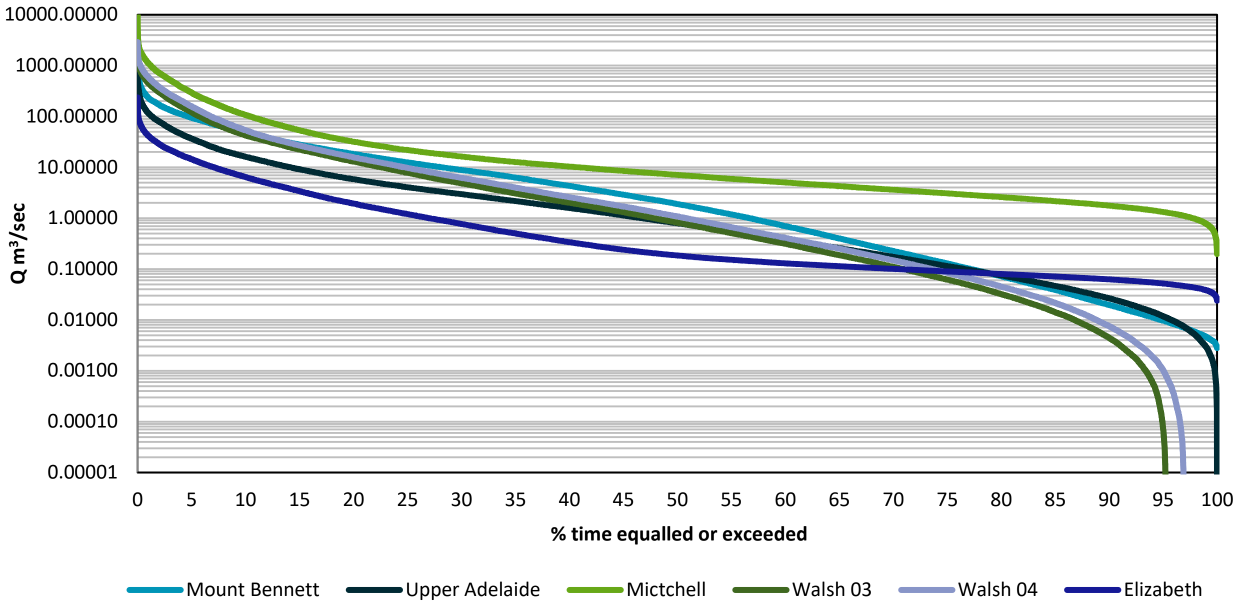
A.12 Walsh 04 – hydropower only energy generation



Apx Figure A-12 Walsh 04 – hydropower only energy generation

Appendix B Duration curves

B.1 Inflow duration curve



Apx Figure B-1 Inflow duration curve

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