Weather radar systems for the Climate Information Services for Resilient Development Planning in Vanuatu

Cost Benefit Analysis

SPREP PROE

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Weather radar systems for the Climate Information Services for Resilient Development in Vanuatu

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Prepared for SPREP

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Executive summary

This document details a cost benefit analysis of investing in a new weather radar for Vanuatu, under the project *Climate Information Services for Resilient Development in Vanuatu*. Weather radar are primarily designed to detect and map areas of precipitation, measuring their intensity and motion, and their type. They can also be used to indicate areas of low-level convergence where thunderstorms may initiate or develop or to detect other phenomena such as volcanic ash, dust storms, insect or bird migrations. Vanuatu does not presently have its own weather radar and existing coverage is limited to the southern part of the country, from radars located and operated out of New Caledonia (Global Environment Facility 2016).

The cost benefit analysis comprises three key components:

- An assessment of the technical suitability of different types of radar for Vanuatu, with particular focus on S band and C band radar, where 'band' refers to the portion of the electromagnetic spectrum – frequency – used by the radar and nominal wave lengths: C band at 4 to 8 GHz, 5 cm; and S band and 2 to 4 gigahertz (GHz), 10 cm.
- An assessment of the economic payoffs of both radar types.
- Consideration of financial issues to sustain a new weather radar over time, including potential revenue streams.

Technical assessment

Based on the review and consultations conducted:

- Both S band and C band radars are used in other Pacific region countries, although the recent favouring of C band systems suggests an increasing availability of local peer support and expertise if the C band system is selected.
- The performance of present-day C band and S band radars in detecting precipitation types and drop sizes are similar, although S band radars may have 'an edge'.
- Due to their smaller size, C band radar are less likely to be damaged by extreme events such as storms or cyclone. This is important considering the frequency of storms and cyclones in Vanuatu.
- Theoretically S band radar has a greater physical range than C band radar (400 kilometres versus 250 kilometres). Although this extra range has limited use due to ground clutter at short ranges, the curvature of the Earth and the widening of the radar beam, it does provide a greater ability to pick up phenomena such as ashfall at longer distances, an issue of note for Vanuatu given its volcanic activity.

Based on the items above, but especially in view of the risk of damage and Vanuatu's exposure to extreme weather events like cyclones, C band radar would appear to offer technical benefits over the use of S band radar, although it will lack the technical capacity of S band radar to detect more distant (>250 kilometres) phenomena such as ashfall.

Economic payoffs

The range of potential benefits of weather radar as a means to inform decision making are wide. For example, radar information may be used to inform: small scale day to day decision making by individuals, agencies and enterprises concerning the weather; small scale localised weather events such as flash floods and local storms; larger scale decision making by individuals and sectors concerning extreme weather hazards; larger scale decision making by governments and investors considering strategic decisions such as investments affected by information on long term weather trends, like climate proofing and engineering works; and planning by sectors concerned with other phenomena that may be detectable by radar such as ashfall, insect or bird migrations.

In practice, the data needed to describe and quantify most of these benefits were not available for this analysis. Data availability was mostly limited to documented extreme events, their impacts and costs, particularly for tropical cyclones. Accordingly, the indicative value of investing in radar was framed as potential cost savings from cyclone events. This provides a window on the *type* and *magnitude* of potential benefit types from radar usage, but not the total values from all benefits.

Based on the analysis, due to the higher outlay and operating and maintenance costs for S band radar, C band radar offer a higher expected return on investment than S band. Using a 6 per cent discount rate over a 20-year period, C band radar was estimated to generate quantified potential savings for TC Pam- and TC Harold-type events[1] of Vt 0.80 per dollar invested, while S band radar was estimated to generate potential quantified savings of Vt 0.40 per dollar invested for the same events[2] (see Table 1).

Table 1: Estimated quantified costs, benefits and payoffs for S band and C band radar over 20 years Vt – 6 per cent discount rate.

Discount rate=6%	Total costs	TC Pam and TC Harold		
Vt$ values discounted over 20 years:		**Total benefits**	**NPV**	**BCR**
C band radar system	325,435,244	263,898,242	-61,537,002	0.81
S band radar system	663,211,412	263,898,242	-399,313,170	0.40

With lower discount rates, expected payoffs increased, with a C band radar coming close to paying off its investment for TC Pam- and TC Harold-type events[1] with a 3 per cent discount rate (Table 2). Similarly, if the number of lives protected per year using radar was assumed to increase from one per year to two, the greater protection of earnings means that C band radar almost paid off its investment over 20 years, for TC Pam- and TC Harold-type events. In both cases, the payoff using S band radar remained lower than for C band radar (Table 3).

Table 2: Estimated quantified costs, benefits and payoffs for S band and C band radar over 20 years Vt – 3 per cent discount rate.

Discount rate=3%	TC Pam and TC Harold		
Vt$ values discounted over 20 years:	**Total benefits**	**NPV**	**BCR**
C band radar system	339,023,833	-23,577,901	0.93
S band radar system	339,023,833	-431,363,518	0.44

[1] That is, if these two events should re-occur.

Table 3: Estimated quantified costs, benefits and payoffs for S band and C band radar over 20 years Vt – 6 per cent discount rate, higher earnings saved.

Discount rate=3%	Total costs	TC Pam and TC Harold		
Vt$ values discounted over 20 years:		Total benefits	NPV	BCR
C band radar system	325,435,244	301,782,794	-23,652,450	0.93
S band radar system	663,211,412	301,782,794	-361,428,617	0.46

Overall assessment

In practice, the estimation of payoffs based on cyclones alone significantly underestimates the potential benefits of radar. Consequently, the estimated returns should be used as the basis for *dialogue*, not as a single decision criterion.

Although lack of data precludes an assessment of radar benefits from day to day and strategic decision making and decisions concerning localised events, it is reasonable to presume that the benefits of both S band and C band radar would amply cover their costs once these benefits and intangible benefits such as wellbeing and improved engineering designs are considered.

Nevertheless, the lower costs, higher durability and more common access to expertise and spare parts in the Pacific region suggest that C band radar would break even sooner, while retaining functionality and access to an increasing set of regional experts and parts. Based on the work conducted, while C band radar lacks the technical capacity of S band radar to detect more distant (>250 kilometres) phenomena such as ashfall, C band radar would seem on balance to offer a better investment than S band radar.

Financial considerations

The Vanuatu Meteorology and Geoscience Department (VMGD) already charges for selected products and services, earning revenue. The considered radar systems are placed to provide the basis for future increased earnings. Based on information collected at the time of writing, potential opportunities for the Department to increase revenue arise from:

- Fine tuning existing charging regimes for aviation services even without radar.
- Charging for new aviation services once radar is established.
- Extending cost recovery to other sectors/ extending commercial services generally.

The establishment of radar nationally is particularly important:

- Presently only three of the approximately 30 airports in Vanuatu (Table 45) pay for meteorological services. The introduction of radar would extend this coverage to the majority of airports and enable the delivery of more weather services and associated charges.
- The introduction of radar would be expected to significantly improve the detection capacity for local storms, lightning and other local phenomena (e.g., ashfall) affecting flight safety. This could be expected to reduce flight disruptions and enable airlines to better flight plan and minimize costs and disruptions. With increased capacity and accuracy, VMGD could aim to increase fee rates.

- Improved detection of flight hazards should provide the basis for future negotiations for a higher share of aviation weather service charges in the Nadi Flight Information Region. Fiji Meteorological Service increased their revenue from the airport authority and airlines due to the radar and improved forecasting of small localised events. Presently, Vanuatu only receives 2.5 per cent of the total Nadi Flight Information Region revenue. With improved accuracy and forecast ability such as now casting, weather service delivery and accuracy could be tracked and provided as evidence for the VMGD to negotiate a higher share of the Nadi Flight Information Region revenue. As an example, a rise in Nadi Flight Information Region fees from 2.5 per cent per year to 3 per cent year alone could cover operational costs for a C band radar. The introduction of radar may also provide an opportunity for the VMGD to ensure that the national distribution of those funds to government departments do reflect the funds attributable to its contribution to those earnings.

With radar, VMGD should be in a strengthened position to consider discussion with new sectors on potential new products and services for revenue. Options might include:

- Direct tailoring of weather data for specific users (e.g. farmers, tourist operators). For example, collaboration with the agricultural sector could perhaps provide scope for the development of tailored weather forecasts for businesses specific to their property.
- The sharing of meteorological/ radar data with commercial agencies for tailoring and on-sale.
- Mobile phone and web applications, along with sales of advertising space (e.g. on the website).

Earnings theoretically could be targeted to VMGD overheads including those associated with radar. At this point, it is useful to reflect that any improvement in Vanuatu’s ability to negotiate funds from the Nadi Flight Information Region would require little adjustment to existing revenue management procedures. The system to collect this revenue and distribute it across government is already place. By comparison, the establishment of new products and associated charging systems would likely involve additional staffing and administration, all of which come at a cost.

1 Introduction

1.1 Climate Information Services for Resilient Development Project

The Climate Information Services for Resilient Development in Vanuatu (known locally as Van-KIRAP – Vanuatu Klaemet Infomesen blong Redy, Adapt mo Protekt) aims to enhance and fill gaps in meteorological, climate and hydrological services. This includes establishing new instruments to augment the observation network, delivering technical skills training for Vanuatu Meteorology and Geo-Hazard Department (VMGD) staff, developing customized climate and information service tools and products for sectors and communities, and establishing effective delivery and communication mechanisms to increase awareness, dissemination and uptake.

The project concept builds on recommendations from the Vanuatu Framework for Climate Services (VFCS) and Government requests of the VMGD. The general scope was developed by a number of organisations including the Government of Vanuatu (Ministry of Climate Change), Secretariat of the Pacific Regional Environment Programme (SPREP), Australia's Commonwealth Scientific and Industrial Research Organisation and the World Meteorological Organization Regional Office in the Southwest Pacific. The project was first proposed at the Pacific Meteorological Council Meeting in 2015 in Tonga (Moirah Matou, Manager Van-KIRAP Project, VMGD, pers. comm., 16 April 2020). The Project is now funded by the Green Climate Fund (GCF) with SPREP as the Accredited Entity.

The Project is intended to support resilient development through the strengthening and application of Climate Information Services in five targeted development sectors:

- Agriculture.
- Fisheries.
- Tourism.
- Infrastructure.
- Water.

In so doing, Van-KIRAP is intended to:

- enhance capacity and capability of national development agents, to understand, access and apply climate and information services,
- enhance climate and information services communications, knowledge products, tools, and resources for practical application to development processes,
- enhance reliability, functionality, utility and timeliness of underlying climate and information services delivery systems and data collection infrastructure, and
- enhance scientific data, information and knowledge of past, present and future climate to facilitate innovative and resilient development.

The project comprises five components:

1. Strengthen the Vanuatu Meteorology and Geohazards Department platform to provide quality climate data and information for climate information services.
2. Demonstrating the value of climate information services at the sectoral and community levels.
3. Development of climate information services tools and engaging with stakeholders through outreach and communication.
4. Strengthening the institutional capacity for long-term implementation of climate information service decision-making.
5. Project Management.

1.2 Objective in this study

This document details a cost benefit analysis of one component of the Van-KIRAP project – the establishment of a new weather radar in Vanuatu. The purpose in the cost benefit analysis is to identify the economic value of investing in alternative forms of weather radar for Van-KIRAP. This information will then be used to inform the selection of radar type for investment and inform its management for optimal use. To this end, the cost benefit analysis in this document focusses solely on the economic value of acquiring, installing and sustainably operating and maintaining a new Van-KIRAP weather radar in Vanuatu, with particular reference to five key sectors, supplemented by other data as practical:

- Agriculture.
- Fisheries.
- Tourism.
- Infrastructure.
- Water.

The detailed Terms of Reference for the analysis are provided in Annex A.

1.3 Layout of this report

The arrangement of this report is as follows:

- Section 1 and 2 briefly outline the Van KIRAP project of which this analysis forms part and provides basic and essential information about Vanuatu that will influence the benefits a radar might generate. It also notes the existing radar capability for Vanuatu and limits in the existing system.
- Section 3 outlines the cost benefit analysis methodology applied in this report and key assumptions and data used.

- Section 4 outlines key radar types for consideration in the Pacific and considers the technical aspects of competing options, including issues of consistency with other Pacific island countries, performance and durability.
- Sections 5-14 detail estimations of potential benefits to different sectors from the introduction of radar.
- Section 15 outlines radar cost and Sections 16 articulate estimates of potential payoffs for investing in different forms of radar under different assumptions.
- Section 17 notes variations in payoff if assumptions are varied.
- Sections 18 and 19 outline key policy considerations for Vanuatu concerning radar usage.
- Conclusions and recommendations are noted in Section 20.

2 Vanuatu

Vanuatu is a Pacific island country located in the South Pacific Ocean. The country is a cluster of 82 islands, spread over 1,300 kilometres (Figure 1). The country is broken into 6 provinces, with the capital and administrative centre of the country, Port Vila, located on the island of Efate in Shefa province, towards the south of the archipelago (Image 1).

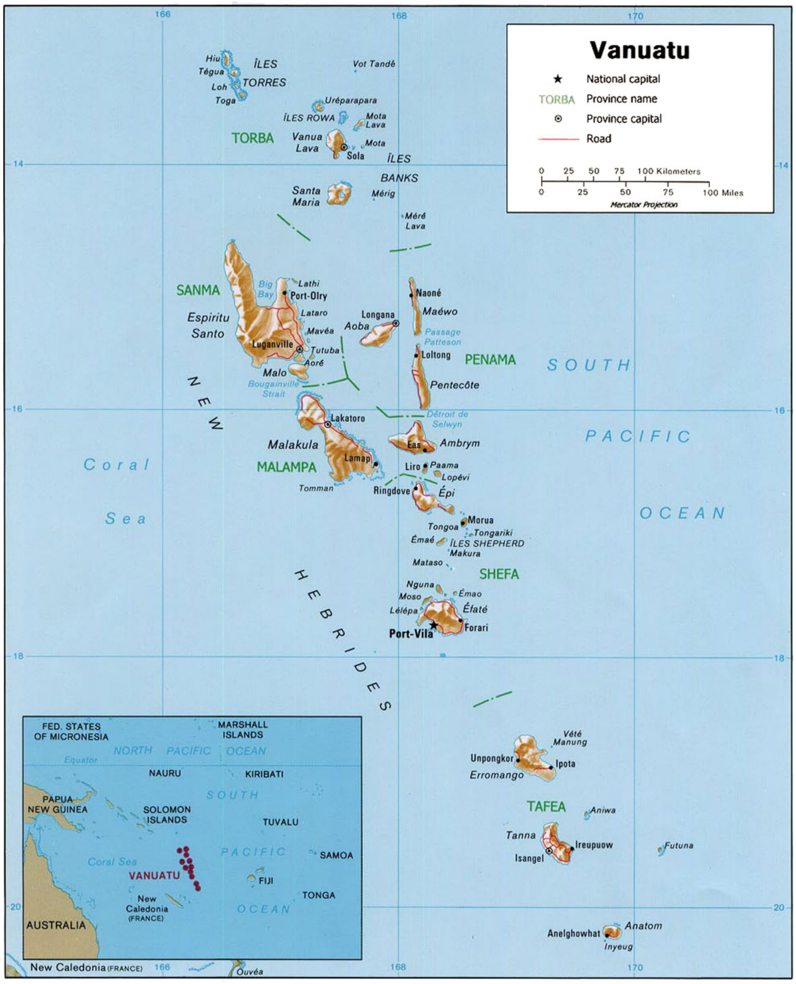

Figure 1: **Map of Vanuatu.** Source: nationsonline.org

The population of Vanuatu has not been formally assessed in recent years. The population in the last formal census was 243,304 (Vanuatu National Statistics Office 2009). Vanuatu National Statistics Office (2013) estimate the 2016 population as 272,459, an increase since 2009 of 16 per cent.

According to the United Nations Department of Economic and Social Affairs[2], Vanuatu is categorised as a Least Developed Country with considerable economic vulnerability. Gross national income per capita is less than half that of developing countries generally (Figure 2) and economic vulnerability is high (Figure 3). According to the Vanuatu National Statistics Office et al. (Undated), wealth across the country is centred in the urban centres of Port Vila and Luganville, with households in Port Vila reporting considerably higher expenditure than households elsewhere in the country (Table 1).

[2] https://www.un.org/development/desa/dpad/least-developed-country-category-vanuatu.html

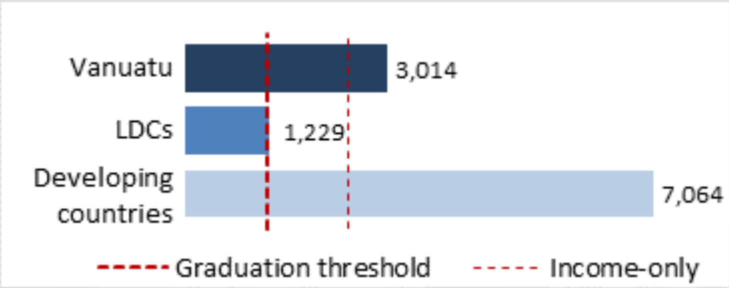

Figure 2: Gross national income (GNI) per capita for Vanuatu. Source: United Nations Department of Economic and Social Affairs Economic Analysis (2018).

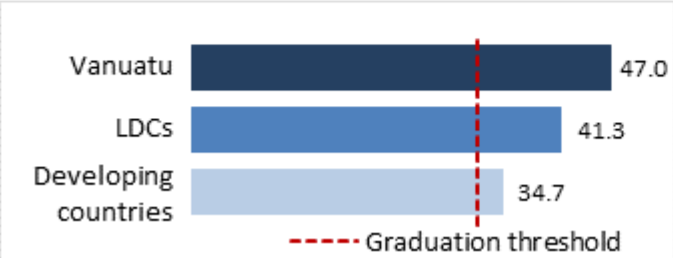

Figure 3: Economic vulnerability Index and Vanuatu. Source:
Source: United Nations Department of Economic and Social Affairs Economic Analysis (2018).

Table 1: Weekly household and adult equivalent average total expenditure in Vanuatu. Source: Adapted from Vanuatu National Statistics Office et al. (Undated).

	Vanuatu	Port Vila (urban)	Luganville (urban)	Rural
Average all Households	17 576	23 711	17 927	15 986
% difference from national household average	-	135	102	91
Lowest Quintile	7 259	11 891	8 424	6 689
Highest Quintile	33 577	42 152	33 874	31 012
VT per capita adult equivalent per week				
Average all households	4 455	4 682	3 903	4 175

Despite households in Port Vila reporting higher expenditure than households elsewhere in the country, Port Vila hosts one third of the country's poorest (Table 2).

Table 2: Distribution of the poor and vulnerable across Vanuatu. Source: Vanuatu National Statistics Office et al. (Undated).

% of all Poor	HH	Proportion of Poor HH by region	Population	Proportion of Poor Population by region
Port Vila (urban)	1 436	27.5	9 123	29.2
Luganville (urban)	524	10.0	3 570	11.4
Rural	3 254	62.4	18 570	59.4

2.1 Hydrometeorological events in Vanuatu

Weather is a daily phenomenon that society in Vanuatu experiences and plans for as part of life. Decisions concerning weather events can range from the daily mundane – shall I travel today or wait for better weather? should I plant today or will the weather be drier tomorrow? – to dealing with less commonly occurring extreme weather events and the need for disaster risk management.

With its exposure to natural hazards such as cyclones and earthquakes and increasing threats from climate change such as sea-level rise, Vanuatu is presently assessed as the country with the highest disaster risk in the world (Bündnis Entwicklung Hilft and The Institute for International Law of Peace and Armed Conflict 2019). Details of past significant weather and climate events in Vanuatu are available from the Pacific Damage and Loss Database (P-DaLo), a comprehensive database describing hazard events and their impacts in Pacific island countries. Applying the UN-established DesInventar methodology, P-DaLo comprises synthesised records of around 1,200 Pacific events that have negatively impacted at least one Pacific Island community. Initiated in 2012, P-Dalo is a living database that is supplemented and evolves on a daily basis. Data presented in this report therefore reflect the contents of P-Dalo at the time of writing.

Across all P-Dalo records, around 1,105 natural hazard-related disasters[3] are documented for the Pacific region, with around 615 reported to have occurred over the 30-year period from 1983 to 2012 (Holland 2013). Damaging natural hazard-related events are dominated by hydrometeorological events. Assuming that landslides are predominantly caused by hydrometeorological events, hydrometeorological disasters accounted for around 75 per cent of all events reported (Holland 2013).[4]

Data from P-DaLo (accessed March 2020) reports 46 officially described hydrometeorological events harming Vanuatu over the 30-year period 1989-2019. Of these, tropical cyclones dominated (Figure 4), accounting for 89 per cent of events reported. The dominance of tropical cyclones in this database is important as it then provides the greatest source of data with which to consider radar benefits. Views supplied by government line agencies conducted remotely over April-May 2020 confirm that cyclones are the weather events of most concern.

The data from P-DaLo indicates that 1.4 tropical cyclones per year make landfall in Vanuatu on average (41 cyclones over a 30-year period)[5].

[3] Does not include epidemics, technical disasters (such as plane crashes, building fires) and so on.

[4] Landslides may be caused by both hydrometeorological and seismic events, but their cause is rarely specified in the records. They may thus be omitted from statistics or attributed for illustrative purposes. If landslides are included in hydrometeorological statistics, hydrometeorological events account for 75 per cent of all natural hazard disasters in the Pacific for the last 30 years. If landslides are instead attributed to seismic events, this proportional falls to 69 per cent. Hydrometeorological events remain more frequently reported in the Pacific in both cases.

[5] This compares with the number of cyclones that pass through the land and sea area of Vanuatu but which may not make landfall. According to VMGD, around two to three tropical cyclones pass through Vanuatu's land and sea areas on average per season (https://www.vmgd.gov.vu/vmgd/index.php/forecast-division/tropical-cyclone#:~:text=On%20average%2C%20Vanuatu%20and%20its,to%205%20causing%20severe%20damage.). By comparison, records have shown that as many as four tropical cyclones have traversed the area of Vanuatu in a single season (Salesa Nihmei, SPREP, pers. comm., 1 July 2020).

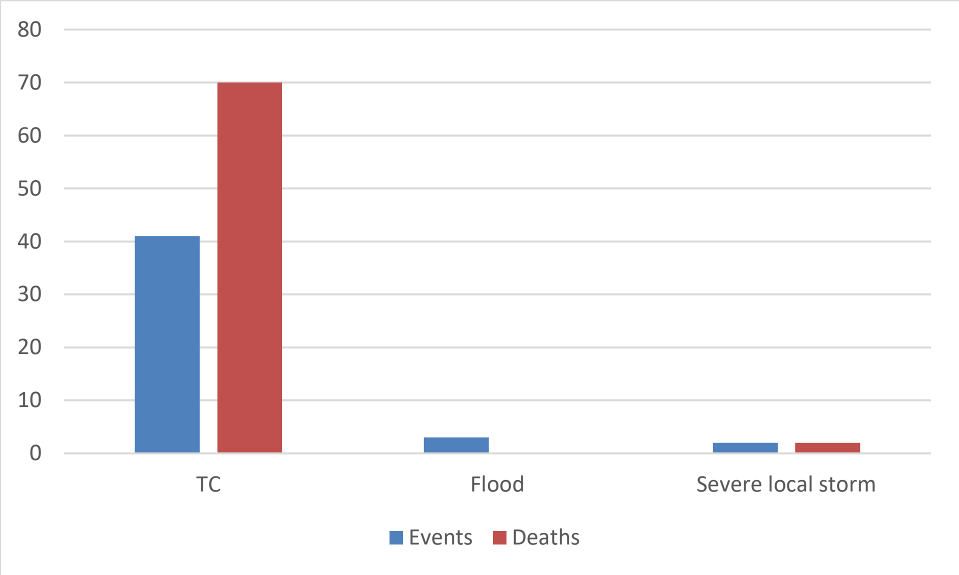

Figure 4: Hydrometeorological events 1989-2019 in Vanuatu. Source: Data extract from P-DaLo, March 2020.

Data from P-DaLo indicates that the number of fatalities associated with hazard events display an upwards trend over time. Significant jumps in fatalities are the result of a severe local storm in 1999[6] and TC Pam in 2015 (Figure 5). P-DaLo records indicate an average death rate from hydrometeorological events of two people per year.

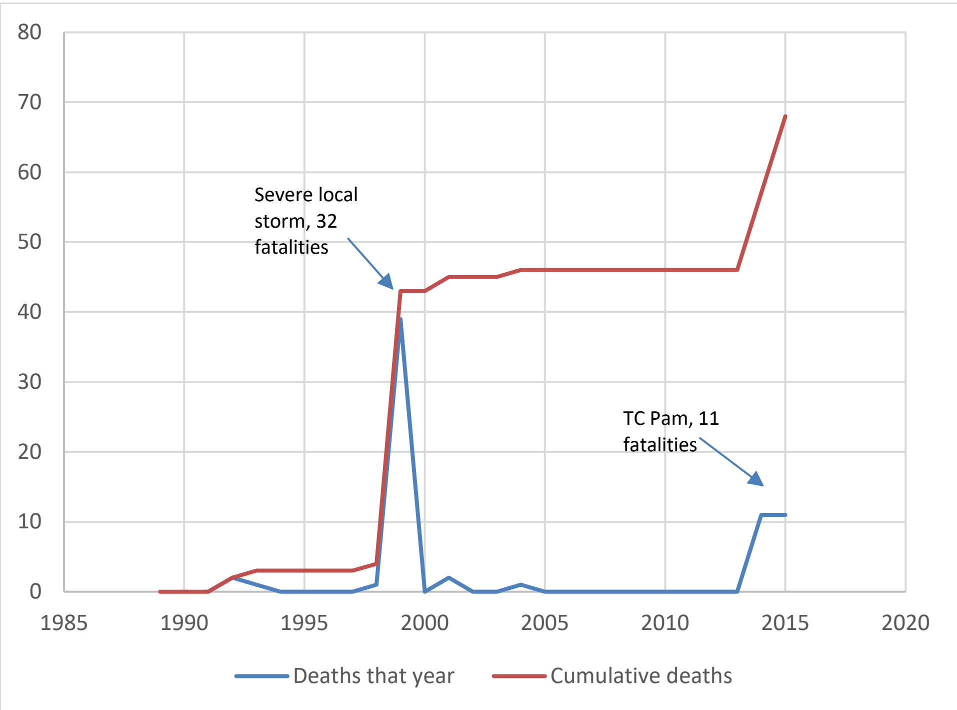

Figure 5: Cumulative fatalities from reported hydrometeorological disasters 1989-2019 in Vanuatu. Source: Data extract from P-DaLo, March 2020.

[6] Extra-tropical cyclone 23F caused heavy rainfall along the east coast of Vanuatu. It generated significant damaging swells that affected most countries within the Southern Pacific for about a week. No damage reports are available for this event.

Severe weather-related events account for the majority of natural-hazard associated deaths in Vanuatu (Table 3). Based on P-DaLo records of 46 hydrometeorological events over 1989-2019, the average number of deaths per cyclone was one person (0.95 people), while hydrometeorological events generally resulted in an average of 2.27 deaths per year.

Table 3: Deaths by event type 1989-2019 in Vanuatu. Source: Data extract P-DaLo, March 2020**.**

Hazard	Total deaths
Flood	1
Severe local storm	32
Tropical cyclone	39
Total	72

Data on the costs of hydrometeorological events are not consistently reported in P-DaLo. Of the 56 hydrometeorological events reported in P-DaLo for Vanuatu for 1982-2012, one third were not accompanied by any assessment of cost (Holland 2014). Of the 46 events found for the 30-year period 1989-2019 in this study, only 17 (38 per cent) recorded any assessment of cost (Table 4). Where assessments of damage costs were collated, the majority of these were for tropical cyclone events.

Moreover, for those events that are valued, the sectors targeted could vary and the method of valuing events has evolving over time, most notably with the introduction of the Post Disaster Needs Assessment (PDNA) methodology recently introduced to the Pacific region. This makes a consistent comparison of the costs of hydrometeorological events over time difficult to achieve.

Table 4: Natural disaster cost omissions for Vanuatu. Source: Review of P-DaLo**.**

Event frequency by PICT	# events	# events costed	# Events not costed	% events not costed
Vanuatu	46	19	29	63

Missing from P-DaLo[7] are weather-related events of a smaller scale. P-Dalo includes reference to only three floods and two local storms over the 30-year period 1989-2019. Detailed reports on the nature of the costs of these five events are not available in the database[8] Other countless localised events in the database are frequently excluded as formal assessment of smaller events is generally not conducted.

The omission of smaller, localised weather-related events from P-DaLo is important for the cost benefit analysis as the Vanuatu community would likely have benefitted from the improved localised information available from radar for their planning and response. In addition, improved weather data from radar might be expected to enable better engineering design for infrastructure such as bridges, roading and or drainage, leading to a reduced need for repair following events. Examples of recent localised events not included in P-DaLo that might have benefitted from radar data are:

- The landslide that affected South Maewo on 12 September 2018, in leading to destruction of 80 per cent of plantations, harm to water sources, heavy damage to several houses (Daily Post 2018b).
- The Ambae flash flood of 31 March 2018 where 30 houses were destroyed and 100 people were affected (Daily Post 2018a).

[7] [7] A dedicated national events database for Vanuatu is presently in preparation but has yet to be populated, leaving P-DaLo the largest source of events data for the country.
[8] Rendering them unusable to estimate possible cost savings

- The hailstorm of 11 October 2016 that affected the Shepherd's group, destroying seven houses, harming trees and threatening root crops (RNZ 2016; Pacific Islands Report 2016).
- The hailstorm that hit southern Tanna on 1 January 2003, harming houses, destroying over 50 percent of food gardens, triggering up to 1,000 landslides, and destroying up to 80 percent of all road crossings (Pacific Islands Report 2003).
- The heavy downpour of March 2001 that caused landslide Liro on Paama island destroying houses.
- The prolonged rainfall of January 2000 that burst the banks of Lake Siwi near the base of Yasur volcano on Tanna Island and washed away a nearby village.

Also missing from P-DaLo may be other harmful weather and related conditions. During its winter months, when the subtropical ridge moves north, intense high-pressure systems that move into the Tasman Sea from Australia generate strong to gale winds over Vanuatu's sea and land area. In both summer and winter months, low pressure systems that formed over the Coral Sea or near New Caledonia and move southeast can generate strong or gale westerly winds. This can be dangerous for people travelling in the open waters. Deep trough systems that form over or within the vicinity of Vanuatu can generate heavy rainfall, either localised or widespread, which can result in heavy rainfall, flooding and landslide (Salesa Nihmei, SPREP, pers. comm., 1 July 2020). These localised systems are presently difficult to forecast without radar.

In 2013, the VMGD reported to the Pacific Meteorological Council that the Severe Weather Forecast Demonstration Project (Met Connect Pacific portal) project enabled Vanuatu to issue targeted services to target risk. The VMGD commenced issue of a warning bulletin called *Severe Weather Warning*. *Severe Weather Warning* covers heavy rainfall (100 mm or more in 24 hours), flooding and inland winds of 20 knots based on satellite imagery as a proxy for radar. They are also able to be ahead of the developments of tropical cyclones. The VMGD emphasises that weather warnings issued for non-tropical cyclone events are equally important as warnings for cyclones (Salesa Nihmei, SPREP, pers. comm., 1 July 2020).

2.1.1 TC Pam

To date, the most comprehensive economic assessment of hydrometeorological events in Vanuatu reflects the costs (damage and loss) of TC Pam in 2015. TC Pam was a Category 5 cyclone with an estimated return period of once every 500 years (PCRAFI 2015). TC Pam resulted in 11 fatalities and the displacement of around 65,000 people (Esler 2015). Following standard post disaster needs assessment (PDNA) methodology, the costs of TC Pam were calculated as either damage (consequences of the event on physical stock (assets such as buildings, belongings or machinery)) or losses (consequences of the event on economic flows, such as higher operational costs or falls in earnings). Esler (2015) reports the total cost of TC Pam to be in the order of Vt 48.6 billion, with tourism and housing worst impacted (Table 5).

Table 5: Costs of TC Pam Vt millions. Source: Esler (2015)**.**

Sector	Damage	Loss	Total costs	% of total event costs
Agriculture and fisheries	1 421	4 641	6 062	12
Commerce and Industry	1 196	2 152	3 348	7
Tourism	5 908	3 610	9 518	20
Housing (Private)	9 452	440	9 893	20
Health	870	107	977	2
Education	3 908	79	3 987	8
Culture	109	3	112	0
Transport	3 017	2 137	5 155	11
Public Buildings	532	12	544	1
Water	414	284	697	1
Energy	179	106	285	1
Communication	2 261	387	2 648	5
Environment	0	5 328	5 328	11
Total event costs	**29 267**	**19 286**	**48 554**	**100**

2.1.2 TC Harold

Other recent events include TC Harold, a Category 5 Tropical Cyclone that made landfall on the island of Espiritu Santo on the 6 of April 2020, and traversed past Ambae, Malekula and through south Pentecost and Ambrym and also affecting Epi island. The cyclone passed directly over Santo forcing hundreds of people to take shelter in evacuation centres. Luganville, a town of 16,000 people, saw roofs blown from houses, trees snapped, and the council building destroyed. There was a general network outage in Banks, Santo, Malekula, Santo and Pentecost (Republic of Vanuatu Public Works Department 2020). At the time of writing, a post disaster needs assessment was underway for TC Harold. The costs, to date, of the event are noted in Table 6, although these values remain preliminary and often partial.

2.1.3 Average annual costs of hydrometeorological events in Vanuatu

Aside from records of singular events such as TC Pam and TC Harold, specific economic data on the costs of hydrometeorological events can be found in the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) hosted at the Pacific Community (SPC). PCRAFI contains a series of datasets related to natural hazard events in the Pacific, including information on assets at risk of disasters (e.g., buildings), information on the impact of historic events and probabilistic models of the costs of natural hazards for Pacific island countries including Vanuatu. (See SPC 2017; http://pcrafi.spc.int/about/.)

Table 6. TC Harold estimated costs Vt..

Sector	Total	Source
Agriculture		Leo (2020)
• Immediate needs	346 060 000	
• Immediate to long term needs	86 900 000	
Infrastructure and works		Government of Vanuatu (2020a)
• Transport infrastructure - damage	1 738 576 206	
• Transport infrastructure – loss	60 866 70	
• Public buildings – damage	1 064 753 630	
Tourism*		Ban (2020)
• Damage to accommodation and restaurants	103 717 000	
• Loss of income from accommodation and restaurants	92 228 000	
• Damage from transportation and tours	15 158 000	
• Loss of income from transportation and tours	7 702 000	
Water and sanitation		Government of Vanuatu (2020b)
• Water and sanitation damage	835 335 839	
• Water and sanitation losses	31 424 119	
Total	**4 321 854 794**	**Partial reports from some provinces, some sectors missing, damage focus.**

* Sanma province only.

According to the Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI) (Litea Biukoto, Manager Disaster Reduction Programme, SPC, pers. comm., 15 April 2020), the average annual costs of all probable tropical cyclones and associated flooding and inundation events in Vanuatu over time are USD$36.8 million and an associated 41 casualties per year[9] (Table 7). The modelled costs and number of fatalities associated with tropical cyclones and their associated effects increases with the severity of the event. For example, a cyclone with a return frequency of 10 years is modelled to generate average annual costs of USD$77 million and 87 casualties, while a cyclone with a return frequency of 100 years is modelled to generate average annual costs of USD$278 million and 293 deaths (Table 7).

2.2 Climate change considerations

PCRAFI and the Australian Government – through its Pacific-Australia Climate Change Science and Adaptation Planning Program – reviewed a series of international climate change models to consider the likely impact of climate change on Vanuatu's weather and climate in the future. Among other things, these suggest that Vanuatu will experience an expected future increase in the relative frequency of tropical depressions, tropical storms and – notably – category 5 storms (Government of Australia Undated).

In the future, the increase in the frequency of such severe weather events might then be expected to result in increased scope to plan for these events, using radar information.

[9] Death and injury.

2.3 Existing and proposed weather radar for Vanuatu

2.3.1 Existing radar system

According to the funding proposal for the project (Global Environment Facility 2016, p. 16):

> *Existing (Vanuatu) Meteorology and Geohazards Department weather, climate and geo-hazard data collection infrastructure assets include five manual weather observation stations, two automatic weather stations (AWS), a Himawari Cast satellite imagery receiving system, two tide gauges, seven seismic stations and 19 warning siren systems. This infrastructure currently supports the Department in collecting data for issuing meteorological and geological forecasts and associated hazard warning to the people of Vanuatu across the expansive Y shaped archipelago consisting of 83 islands. This infrastructure is not however considered adequate to provide national coverage of real-time, high resolution data to inform climate and information service-based climate and early warning services during severe weather events such as tropical depressions/cyclone resulting in extreme wind and rain and associated extreme sea level events (storm surge and coastal inundation).*

One of the present gaps in the Vanuatu weather and climate infrastructure is weather radar. Weather radar are primarily designed to detect and map areas of precipitation, measuring their intensity and motion, and their type. They can also be used to indicate areas of low-level convergence where thunderstorms may initiate or develop or to detect other phenomena such as volcanic ash, dust storms, insect or bird migrations.

Present radar capability in Vanuatu is limited to coverage in the southern part of the country, from radars located and operated out of New Caledonia (Global Environment Facility 2016). The VMGD (Moirah Matou, Manager Van-KIRAP Project, VMGD, pers. comm., 22 April 2020) advise that the New Caledonia radar only covers Erromango and Tanna islands in Tafea province. This includes Whitegrass Airport although Nouméa radar support here has to be used alongside satellite imagery for verification, as it only captures high and mid-level clouds (Moirah Matou, Manager Van-KIRAP Project, VMGD pers. comm., 2 July 2020). It does not cover the smaller Tafea offshore islands or any other islands in the Vanuatu archipelago. Additionally, SPREP indicate that this service is not utilised during cyclone operations (Philip Malsale, SPREP, pers. comm., 22 June 2020).

According to the 2009 census of Vanuatu, Tafea province hosted around 32,540 of the country's total 234,023 residents in 2009 (Vanuatu National Statistics Office 2020b) – around 13.9 per cent of the national population. As indicated in Section 2, no census has taken place since this time. However, applying the 2016 national population estimate of 272,459 (Vanuatu National Statistics Office 2013), Erromango and Tanna islands should presently host around 40,247 residents, leaving over 270,000 ni-Vanuatu without present radar coverage (Table 8).

Table 7: Modelled average annual costs of tropical cyclones and associated flooding and inundation for Vanuatu. Source: PCRAFI model, Litea Biukoto, Manager Disaster Reduction Programme, SPC, pers. comm., 15 April 2020**.**

		Probability of exceedance*								
	Annual average loss	2	5	10	20	40	50	65	90	99
Costs USD	36,786,029	642 021 500	545 233 100	454 918 800	359 438 860	278 318 620	244 945 440	206 305 870	129 064 490	76 443 747
Casualties	41.30	595.60	522.10	449.12	366.88	292.50	260.60	222.68	143.46	86.74

*Probability of exceedance. There is a:

2 2% probability that this value will be exceeded in 50 years (2475-year event)
5 5% probability that this value will be exceeded in 50 years (975-year event)
10 10% probability that this value will be exceeded in 50 years (475-year event)
20 20% probability that this value will be exceeded in 50 years (224-year event)
40 40% probability that this value will be exceeded in 50 years (100-year event)
50 50% probability that this value will be exceeded in 50 years (72-year event)
65 65% probability that this value will be exceeded in 50 years (50-year event)
90 90% probability that this value will be exceeded in 50 years (22-year event)
99 99% probability that this value will be exceeded in 50 years (10-year event)

Table 8: Population coverage of present radar for Vanuatu.

Island	Population in 2009 census	Approximate population in 2016
Erromango (covered)	1 959	2 281
Tanna (covered)	29 000	33 763
Rest of Vanuatu (not covered)	203 064	236 415
Total	**234 023**	**272 459**

2.4 Weaknesses in the present system

In addition to existing coverage gaps, the World Meteorological Organization (2015b) describe the services and structure of the VMGD. They note existing challenges in the Service (Box 2).

Box 2: Challenges and gaps of the Vanuatu National Multi-Hazard Early Warning System

Limited coordination between the Vanuatu Meteorology and Geohazards Department (VMGD) and some stakeholders:

- There is a need to develop a close relationship between the VMGD and all private radio stations and other media organizations[10].

Limited current skill and capacity of the VMGD staff:

- The limited current level of skill and capacity to couple the meteorological NWP and ensemble models with other hazard models and hazard mapping meant that the severity, timing and extent of the associated hazards (storm surge, landslides and flooding) were underestimated[11].
- Lack of capacity to translate hazard information into impacts meant that impacts were under-estimated by some communities.

Non-existing verification tools in data-processing and forecasting system leads to limited knowledge of the VMGD on quality and reliability of warnings:

- Lack of objective verification of forecasts may have resulted in lack of knowledge of the quality and reliability of forecasts and warnings.

Inadequate safety of the VMGD staff during tropical cyclone events:

- Safety of staff undertaking operational work during cyclone events and other severe weather events is a major concern. VMGD Offices in the outer-islands and provinces are not built to high and cyclone-proof standards and staff members at risk if they are on duty during severe cyclone events.
- Staff required to work during severe cyclone events can be distracted over concerns for the safety of their families.

Limited communication system for exchange of information including warnings between the VMGD Headquarters and Offices in the outer-islands and provinces:

- Communications of data between the VMGD Headquarters and its Offices in the outer-islands and provinces needs to be modernized through utilization of the digital communications networks now in place across Vanuatu[12].

Non-response by communities due to lack of understanding of warnings and associated impacts:

- Category 5 cyclones are rare events and therefore some communities did not clearly understand the likely impact of such a severe disastrous event.
- Lack of understanding of the warnings by the public due to the use of scientific jargon, failing to communicate the severity and urgency in the warnings may have led to inadequate response by the communities and public.

[10] VMGD state that efforts to address this are presently underway including the targeting of memoranda of understanding.
[11] VMGD observe that there is a large number of WMO class 1 officers working at the Division and consider that the bigger issue here is actually that the tools that are being used are not high enough resolution to enable precise weather forecasts for each island/area.
[12] This issue is presently being address with the establishment of network communications by the V-CAP project. However, the contracts for this service have now expired so data is no longer coming in. Nevertheless, VMGD is working on this to revive the arrangement.

No-response to warnings due to other factors:

- Cultural habits and beliefs may have contributed to non-action on the part of the recipients of cyclone information, advisories and warnings.
- Lack of engagement of social sciences to understand behaviours and decision-making processes of the population has a role in lack of proper response.
- Inconsistency between public and marine forecasts and cyclone information, advisories and warnings might have contributed to communities and public confusion.
- Limited tailored services for different sectors, e.g., land transport and marine.

Advance information of tropical cyclones from other sources:

- Competition including advance information and wider coverage of the region from non-competent and/or multiple service providers leading to public confusion during times of disaster events.

Inadequate observing networks and data:

- Spatial distribution of existing observing networks across Vanuatu is inadequate. There is a need for additional synoptic weather observation sites through the northeast of the country.
- The rain gauge network is less than adequate and a wider network would provide an adequate basis for flood warning services associated with tropical cyclones approaching land.
- Temporal frequency of observations needs to be significantly improved. The replacement of manual observations with automatic observations is seen as a high priority. The Government of Vanuatu is presently seeking to address this issue through the acquisition of automatic weather stations via the RESPAC, V-CAP and Van KIRAP projects as well as through the acquisition of radar through the Van KIRAP project.

2.4.1 Proposed new radar

Discussions concerning a new radar for Vanuatu under the Van KIRAP project have focussed on the idea of installing the new radar on Snake Hill, Efate. The details of the instalment have yet to be determined although negotiations to secure the land have commenced. As the selection of radar relies in part on the economic analysis in this document, the technical nature of the radar (e.g., Range) has yet to be agreed. Discussions have included the potential use of C band and S band radars (see Section 5.1 for more information).

The VMGD consider that the establishment of a new radar will enable the generation of near precise rainfall data. Presently, the VMGD weather infrastructure and climate infrastructure is not considered adequate to provide national coverage of real-time, high resolution data to inform climate and early warning services during severe weather events (SPREP 2019). With the establishment of new radar operations, the VMGD anticipate that rainfall thresholds for flooding can be established in all islands and warnings of flooding and landslide risk provided in advance. They expect that the new radar would then enable early warnings of flooded roads. As an example, the VMGD (Moirah Matou, Manager Van-KIRAP Project, VMGD pers. comm., 16 April 2020) note that trucks on Tanna become stuck and damaged around Lake Siwi (Yasur) each time the creek nearby overflows. Radar generated information would enable VMGD to issue more timely information and increase public awareness that the creek has flooded to enable the area to be avoided. In all likelihood, the improved data would also be expected to enable better engineering design for infrastructure leading to a reduced need for repair.

The location of the radar on Snake Hill, Efate, would also contribute information to the safety of both domestic and international planes departing, arriving or refuelling planes at the Bauerfield Airport. The location is near Port Vila, the capital of the country and where most vital infrastructure are located.

3 Methodology

This assessment has been conducted using a standard cost: benefit framework. Cost benefit analysis (CBA) is a systematic process for identifying, valuing, and comparing costs and benefits of a project. Multiple references exist on the methodology and principles of CBA (see, for example, ADB 2017; Australian Government Department of Finance 2006; OECD 2006; Tietenberg 2006; HM Treasury 2003; European Commission 1997, 2008). However, broadly speaking, the key features of a CBA are:

- all related costs (losses) and benefits (gains) of a project are considered, including potential impacts on human lives and the environment
- costs and benefits are assessed from a whole-of-society perspective, rather than from one particular individual or interest group (that is, a public and not a private perspective is taken)
- costs and benefits are expressed as far as possible in monetary terms as the basis for comparison, and
- costs and benefits that are realised in different time periods in the future are aggregated to a single time dimension (discounting) (Buncle et al. 2013).

The first issue of considering all costs and benefits from a project is fundamental to effectively interpreting any CBA. In theory, all the potential benefits and costs of radar application would be assigned dollar figures when doing a CBA. This would be founded on empirical impact assessments of previous events, the likes of which radar information would inform. However, as is common for many cost benefit analyses, lack of data precluded the quantification of all the benefits or costs of radar:

- Radar benefits rely on the degree to which radar data will be converted into information and subsequently taken up by users to change their behaviour and well-being. In practice, it can be difficult to quantify ex ante the change in social wellbeing arising from radar data because the degree of data conversion and information uptake are not known in advance.
- It was only after Cyclone Pam and the introduction of Post Disaster Needs Assessments that sectors commenced regular data collection of the impacts (costs) of natural hazard events that might benefit from radar information for planning and response. Prior to this, event assessments focussed understandably on humanitarian needs and little sectoral cost (economic impact) data was collected (Moirah Matou, VMGD, pers. comm., 13 May 2020) and any assessments that were conducted varied in form and content e.g., flyovers and descriptive assessments, plans for the distribution of relief supplies or, in some cases, recommendations for specific replacement work/ treatments. The resulting data is therefore often not consistent, even post 2015.

  This gap is important in estimating the probable payoffs from a new radar system. Ideally, the average annual costs to Vanuatu of different sized weather events would be used to estimate a relationship between hydrometeorological events of different probabilities and expected costs. The estimated annual costs across all probabilities would then be calculated to determine average annual costs with and without radar. In practice, such data in a consistent form was not available for Vanuatu.

- In the case of this specific analysis, data collection was further hampered by the onset of Covid-19 in the Pacific region and the occurrence of TC Harold. Covid-19 rendered site visits for consultations with key agencies impossible and TC Harold created new priorities for the Government of Vanuatu. It is probable that more data would have been collected, had these events not occurred.

To this end, the analysis applies a variety of approaches to provide some estimate of benefits and costs – as agreed with SPREP:

- Builds from a technical assessment of radar options and their suitability for Vanuatu, with minimum service needs used to identify potentially suitable equipment. The most cost-effective suitable equipment to deliver this information is identified. This information is supplemented with information on likely impacts of the technology, quantifying impacts where reasonable.
- Indicates the potential savings that might be secured if events that happened in recent years were to occur again with a radar.
- Includes illustrative scenarios. Where it is not possible to identify in advance the reduction in harm occurring in – say – losses to primary production such as increased operating costs – illustrative rates are used where reasonable to indicate the scale of potential increases in wellbeing possible from radar application.
- Includes descriptions of benefits and costs that cannot reasonably be quantified in the timeframe of the analysis. For instance, the impacts of reduced trauma by avoided harm is commonly not quantified using monetary terms as the methods for valuing intangible benefits requires highly detailed and data-hungry analysis (such as choice modelling).

3.1 Using tropical cyclones to consider radar benefits

The assessment focusses on the use of tropical cyclone events only to consider the benefits from radar dues to:

- the lack of availability of data on localised weather events, and
- the relative availability of data on cyclones, and
- the fact that cyclones were the weather event most line agencies mentioned as a prime concern for them.

The analysis indicates the *types* of sectors that may benefit from improved weather information and the kinds of benefits that may arise. In practice, radar may additionally benefit:

- Small scale day to day decision making by individuals, agencies and enterprises concerning the weather.
- Decisions relating to small scale localised weather events such as flash floods and local storms.

- Larger scale decision making by individuals and sectors concerning extreme weather hazards.
- Larger scale decision making by governments and investors considering strategic decisions such as investments affected by information on long term weather trends.
- Potentially, other sectors that may benefit from the detection of phenomena such as insect or bird migrations.

As a result, the potential benefits from cyclone planning and response reflects only a fraction of the possible benefits from radar information (Figure 6). This means that resulting values represent only a portion of the benefits of applying radar data. The estimated payoffs will be a minimum and conservative.

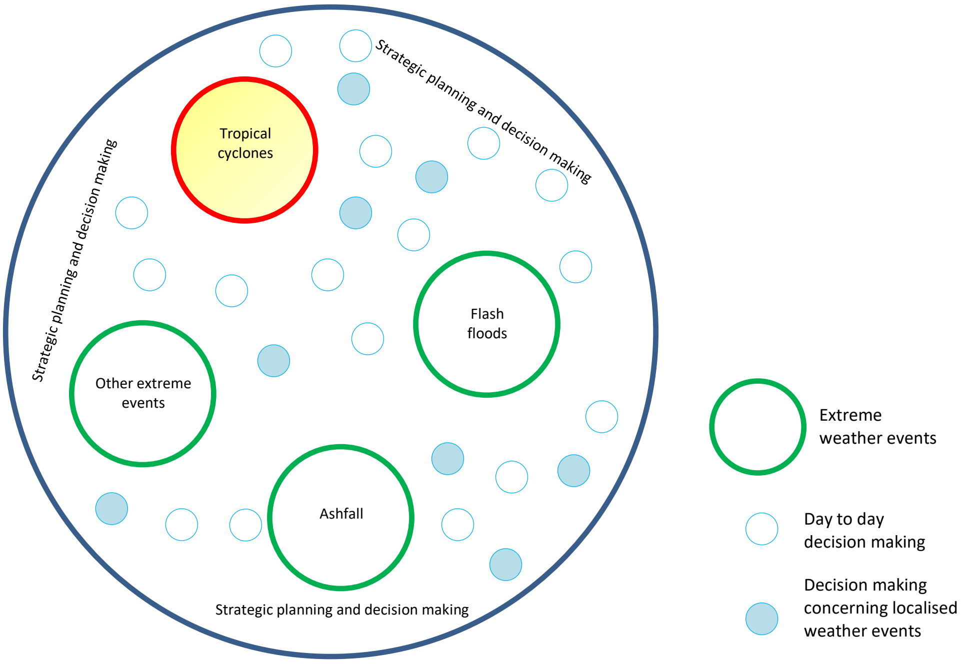

Figure 6: Cyclone risk management as a portion of weather-related decision making.

3.2 Steps followed

The following steps were taken.

- Information was sought to estimate the annual cost of events across all probabilities. However, existing accessible documentation precluded the establishment of a useful relationship. Instead, tropical cyclone costs across all probabilities were taken from the PCRAFI model where they already existed for a sector (e.g., building damage).
  - Where insufficient information existed on the annual cost to a sector across all probabilities, the reported costs from a single hydrometeorological (cyclone) event (e.g., TC Pam) were used to indicate costs to a sector.
- The annual cyclone costs avoided were assigned across each year of the project, discounted and summed to estimate the benefits of investing in the different protection options.

- The annual tropical cyclone costs avoidable through the use of radar data were estimated by multiplying total sector costs by a cost reduction factor. Functions were taken from estimations by sector representatives and from the literature (see Section 3.3 below).
- The costs of radar options were subtracted from the estimated benefits of radar benefits to estimate net present value and benefit: cost ratios.
- Key benefits and costs that were not quantified were highlighted.

3.3 General assumptions

3.3.1 Cost reduction functions arising from weather and climate information

Estimates of the potential scale of avoidable harm resulting from weather and climate warnings commenced with work by Day (1970, Figure 7) who estimated the likely impact of event lead times on the protection of personal effects. Day estimated that a lead time of 24 hours could result in reduced damage to personal effects of 30 per cent, rising to 35 per cent if the warning was increased to 48 hours. Day's predictions presumed a 100 per cent public response rate for potential benefits to be secured. This may not always be possible in Vanuatu due to the remoteness of some locations and/or limited connectivity with phones, radio or other media access. As a result, this formula can be used to estimate potential savings from improved meteorological services although the values would need to be conservatively applied.

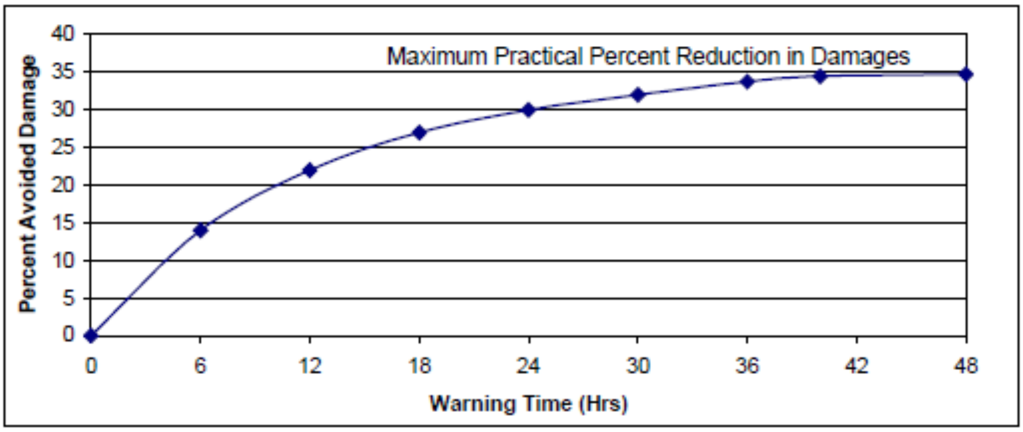

Figure 7: Lead time damages prevented curve. Source: Day (1970).

More recently, Subbiah et al. (2008) drew on field observations and consultations to propose a series of reductions in damage that can be achieved in a variety of sectors, including household possessions (Table 9). Fakhruddin et al. (2019) applied these reductions to estimate potential savings from early warnings in the Pacific (Samoa). In this case, Fakhruddin et al. (2019) modified the calculations to reflect the concept that short term (less than 10-day) forecasts might be presumed to be 90 per cent accurate, generating 80 per cent of potential benefits.

3.3.2 Timeframe

The timeframe for the analysis is based on the expected life of the radar equipment. This is assumed as 20 years.

3.3.3 Discount rate

Recognising that the costs and benefits of investments accrue variously over a time period, this cost benefit analysis involves the discounting of benefits and costs to render them to a common metric – their present value. This is standard for cost benefit analysis. Discount rates applied across the Pacific have varied widely in recent years. Buncle et al. (2017) observe that rates applied in recent years vary from 3 to 15 per cent. The rates also vary for international agencies such as the EU (commonly hovering around 4-8 per cent) and the World Bank or Asian Development Bank (hovering anywhere between 9 and 12 per cent depending on the investment issue).

For this study, a discount rate of 6 per cent is applied, consistent with development rates from Australia (Australian Government Department of Finance, 2006). A sensitivity analysis was conducted at 3 per cent.

Table 9: Damage reduction due to early warning of different lead times [a]. Source: Subbiah et al. (2008).

Item	Lead time	Damage reduction (%)	Actions taken to reduce damages
Household items	24 h	20	Removal of some household items.
	48 h	80	Removal of additional possessions.
	Up to 7 days	90	Removal of all possible possessions, including stored crops.
Livestock	24 h	10	Poultry moved to safety.
	48 h	40	Poultry and farm animals moved to safety.
	Up to 7 days	45	Poultry, farm animals, forage and straw moved to safety.
Agriculture	24 h	10	Agricultural implements and equipment removed.
	48 h	30	Nurseries and seed beds saved, 50% of crop harvested, and agricultural implements and equipment removed.
	Up to 7 days	70	Nurseries and seed beds saved, fruit trees harvested, 100% of crop harvested, and agricultural implements and equipment removed.
Fisheries	24 h	30	Some fish, shrimps and prawns harvested.
	48 h	40	Some fish, shrimps and prawns harvested, and nets erected.
	Up to 7 days	70	All fish, shrimps and prawns harvested, nets erected, and equipment removed.
Open sea fishing	24 h	10	Fishing net and boat damage avoided.
	48 h	15	Fishing nets removed, and boat damage avoided.
School or office	24 h	5	Money and some office equipment saved.
	48 h	10	Money and most office equipment saved.
	Up to 7 days	15	Money and all office equipment, including furniture, protected.

[a] Field observations

3.4 Realisation of benefits

The benefits of new meteorological services and data can be expected to increase over time as a result of the learning curve or lagged adoption. In the beginning, operators will require training to learn how to operate, interpret and maintain new radar systems. It may even take time for users to trust the new service enough to make economic decisions or determine how to best respond to it (World Meteorological Organization, 2015a). To reflect this delay, it is assumed that only 50 per cent of potential benefits will be realised in the first year of operation, but and that this will rise to 100 per cent in following years.

3.5 Data

Data for this analysis is taken from:

- PCRAFI.
- Published literature and data including previous records of the impact of major hazard events including the post disaster needs assessment for TC Pam that occurred in 2015.
- Views of key stakeholders about the scale/ probability of climate related hazard events and or the impact that improved warnings could have for constituents in key sectors, and/or
- literature, quotes and information requests to sector experts on radar.

4 Radar options

Weather radar provide real-time weather forecasting, especially for severe and localised weather. They are able to detect weather events at multiple scales, for example, local cells to tropical cyclones, with high resolution and fast updates. The wide range of coverage of radar means that the tracking of weather across areas can assist in the generation of data and modelling for climate and longer-term phenomena (such as El Nino and La Nina), as well as local weather events.

There are three core types of weather radar applied globally: X band, C band and S band, where ‘band’ refers to the portion of the electromagnetic spectrum – frequency – used by the radar and nominal wavelengths:

- X band: 8 to 12 gigahertz, 3 cm.
- C band: 4 to 8 gigahertz, 5 cm.
- S band: 2 to 4 gigahertz, 10 cm.

A radar is a highly effective observation system, but a single radar cannot be designed to be the most effective for all applications and cost is a significant consideration.

Radar rays are attenuated (weaken with distance) most significantly in rain, and much less so in clouds. Attenuation of X band, C band and S band radar varies. X band radars have high attenuation, up to 30 times that of S band radar. Compared to S band and C band radars, they also have a limited range (see more below). X band radar are limited to around 100 kilometres and their range can be as low as 30 kilometres for reliable quantitative measurements. These characteristics mean the X band radar is largely seen as a gap filler for, and complimentary to, C or S band radar networks. It means they currently have limited use in Vanuatu and are excluded from further consideration within the scope of this document.

Broadly speaking, attenuation at the S band is less than for C band, making them ideal in tropical conditions such as those in Vanuatu. However:

- S band weather radars need more powerful transmitters for comparable sensitivity to C band radar rendering it more expensive, more demanding of space and more demanding of electricity.
- S band radar are much larger than C band radar. Typical antennae for S band radar involve an 8.5m diameter parabolic reflector at S band compared to a typical diameter of 4.2 – 4.5m diameter for C band. This in turn necessitates a bulkier and heavier positioner (pedestal), a larger radome, a more expensive tower and more laborious installation.

The result of these demands is that, while S band radar may be preferred for forecasting purposes, they are more expensive than C band systems.

4.1 Radar types in the Pacific

At the global level, C band and S band weather radar are the more common types in use and are the cornerstone of large meteorological observing networks. While X band weather radar is relatively new and has offers very high resolution, it nevertheless has a much a smaller range and is typically used for infilling of existing networks. X-Band tends to be most suited for large urban areas and for complementing existing networks. For the Van-KIRAP, the limitations make it less of a viable option than the C band or S band radars.

In the Pacific region (World Meteorological Organization Region V), a combination of S band and C band systems are presently in use:

- Australia have a mix of C band and S band and are in the process of upgrading their network and retaining the mix.
- New Caledonia has three C band radar.
- Fiji has one C band and two S band radars. They are in the process of replacing the S band with C band radars.
- PNG has C band radar.
- New Zealand have a mix, but all recent and new installations are C band.

Overall, either an S band or C band radar system would be consistent with other systems applied in the region. However:

- With New Caledonia utilising the C band radars and having a close connection with Vanuatu, there would potentially be value in targeting the same equipment as New Caledonia for the potential pooling of spare parts and technical support such as guidance in repairs and maintenance.
- The recent favouring of C band radar systems in other Pacific region countries would suggest an increasing availability of regional peer support and expertise if the C band system was used in Vanuatu.

4.2 Technical expertise

The existing Information and Communications Technology division within VMGD is presently strong and, according to the Department, involves a large number of WMO class 1 officers (Philip Malsale, SPREP, pers. comm., 22 June 2020). While a weather radar in Vanuatu would represent a significant new piece of equipment, the requirement for capacity development to operate and maintain it is well understood by VMGD. Moreover, capacity development is provided for in the original funding proposal under Activity 1.7. Information supplied for this analysis indicates that the VMGD plans to employ a new radar technician in addition to training existing Information and Communications Technology staff. Technical support is also available from neighboring countries such as Australia, Fiji, New Caledonia and New Zealand. In this respect, technical development to operate either an S band or C band radar would seem to be catered for although, as indicated already, the recent favouring of C band radar systems would suggest an increasing availability of regional peer support and expertise.

4.3 Performance

S band weather radars have been traditionally favoured in the tropics since the S band signal is nearly immune to attenuation in heavy tropical rainfall. The level of attenuation increases sharply as the wavelength shortens. For a given intensity of rainfall, signals at the X-band (3.2 cm) attenuate 30 times more than signals at the largely unattenuated S band (10 cm). The phenomenon remains relatively moderate at the C band (5.4 cm) with an attenuation factor of less than four compared to S band.

While S band radars were historically more suitable in tropical regions, recent developments such as the development of dual polarization radar technology for C band radars means there is now little difference in capability between C band and S band radars. For example, dual polarized C band radars can now distinguish between precipitation types in clouds, analyse raindrop size, and identify the presence of supercooled water droplets which can cause icing problems for aircraft. The result is radar observations of very similar overall performance to S band radar observations.

S and C band radars offer different coverage. Theoretically, the typical operational range for S band radar is 400-600 kilometres, while it is only 200-250 kilometres for C band radar. However, owing to ground clutter at short ranges, the Earth's curvature and the widening of the radar beam, quantitative precipitation detection more than 100 kilometres away from the radar is possible only to a limited extent and the maximum practical range for weather observation by both radar type is actually only around 200 kilometres (WMO, 2018). A material difference in radar capability with the range differences is potentially the greater ability of the S band radar to pick up phenomena such as ashfall at longer distances, an issue of note for Vanuatu given its volcanic activity[13]. Otherwise S and C band radar are limited in detailed detection to similar ranges.

As a broad indication of the meaning of this span, a radar with a 250-kilometre coverage would cover most of Tafea, Shefa, Malampa and part of Penama provinces, but would leave Sanma and Torba outside the range, while a radar with a 400-kilometre range would cover all provinces except for Torba (Figure 8).

Based on these broad ranges, a 250-kilometre radar would increase coverage from an estimated 40,247 residents persons presently (12 per cent of the population) to approximately 195,189 people – increasing coverage from 12 to 72 per cent of the national population[10]. This would occur with both S band radar and C band radar. However, S band radar could theoretically increase the range for select phenomena such as ashfall as far as 400 kilometres, extending coverage to around 262,307 people, 96 per cent[14] of the national population.

[13] Examples of key ashfall events include the long run Ambae volcanic eruption and volcanic ash impact over 2017-2018. Response needs (damage) for this event were variously assessed as being between Vt 502,394,889 (Government of Vanuatu 2018c) and Vt 4,513,071,577 (Vanuatu National Disaster Management Office 2018), depending on the time of the assessment. Nevertheless, detailed cost assessments of ashfall are not common. Complicating the assessment of ashfall events is the fact that P-DaLo does not include ashfall as a dedicated event category.

[14] Based on the 2016 population values and applying the national population increase to the island of Pentecost.

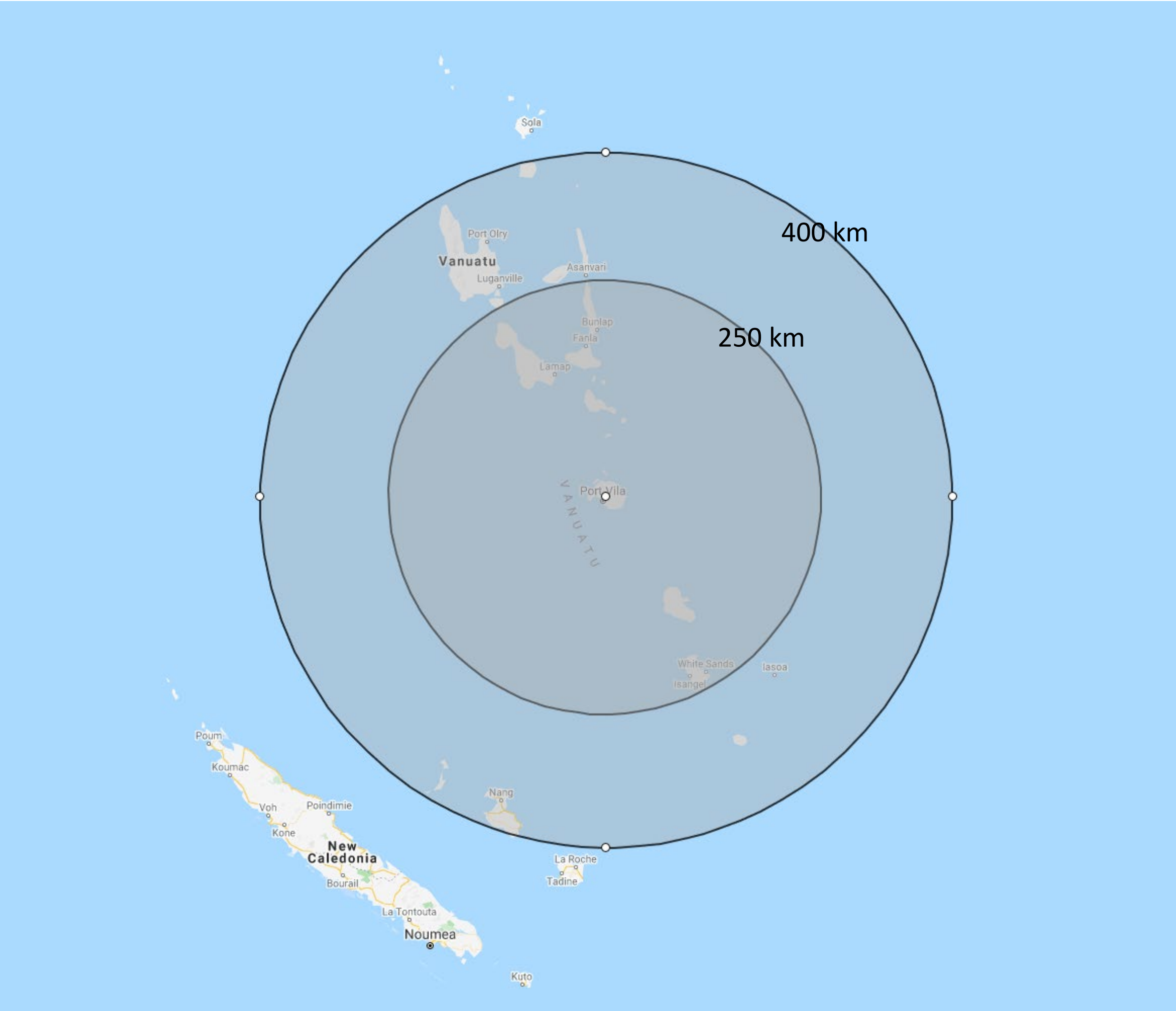

Figure 8: Indicative radar range at 250 kilometres and 400 kilometres.

Durability of instrument during cyclones

Weather radar are usually installed atop a relatively high tower (10-30 m), where the radome covering radar antenna pedestal system is exposed to high wind speeds. In areas where tropical cyclones and storms exist, the durability of instrument is important. Specifically, reinforced radome and tower structures are applied in cyclone-prone areas. A damaged radar radome during a tropical storm event usually results in a completely damaged radar antenna-pedestal, leaving end users without radar information.

At minimum, the restoration of a damaged radar requires the replacement of radar radome and antenna pedestal but may also require the replacement of the entire radar system. The cost of the repair can be estimated as 50-100 per cent of the price of entirely new radar system.

The type of the radar (S or C band) affects significantly the risk of damage during tropical storms. This is due to different weight and dimensions of C and S band radar system. An S band weather radar, with a typical antenna diameter of 8-9 m, requires a radome of 10-12 m in diameter, while a C band radar with 4.2-4.5 m antenna, requires a smaller radome approximately 6-7 m in diameter. From an engineering perspective, it is significantly more challenging, and expensive, to build a S band radar tower and radome that can withstand high wind speed and the impact of flying debris in tropical cyclones.

A recent example of the survival capability of radar equipment during a tropical storm is category 5 Hurricane Maria of September 2017 (US NWS categorisation) where high wind speeds of up to 280 km/, tore down an operational S band weather radar in Puerto Rico (the radar was part of the US NEXRAD weather radar network operated by US National Weather Service).

Table 10: Summary of basic considerations.

Feature	S band	C band
Consistency with other Pacific radar	Mixed	
Attenuation	Very low.	Very low with dual polarization*.
Durability	Lower (higher risk of damage during tropical storms due to the need for a larger tower and radome).	Higher (lower risk of damage during tropical storms due to the need for a smaller tower and radome).

* Leading to similar overall performance compared to S band radar observations.

5 Agricultural sector data

According to Sleet (2019), around 80 per cent of the population of Vanuatu relies on agriculture for livelihoods and food security. The sector also generates around 20 per cent of Vanuatu's GDP (Table 11). Mackenzie-Reur et al. (2018) state that Vanuatu's agriculture sector is divided into three distinctive subsectors[15], with the subsistence sector accounting for more than 75 per cent of the total agriculture production. They note that the subsistence subsector is predominantly centred on root crops (taro, yam, cassava and sweet potato) for consumption and cultural purposes (e.g., ceremonies) and characterised by a total reliance on rain irrigation and rudimentary tools (Mackenzie-Reur et al. 2018).

Based on the contention that subsistence sector accounts for more than 75 per cent of the total agriculture production (Mackenzie-Reur et al. 2018), the total value of agricultural production in Vanuatu in 2017[16] would be in the order of Vt 81.2 billion, with the subsistence sector accounting for around Vt 60.8 billion.

Early warnings for the agricultural sector enable the reduction of losses and some damage from agricultural harm related to weather events. For example, if well communicated to farmers:

- Seasonal forecasts can inform what to plant and or when – for example, farmers might target more drought-tolerant crop varieties in the prospect of low rainfall or switch foodstuffs for livestock, thereby reducing the scale of harm to crops and livestock.
- Radar data can inform localised events arising from longer term phenomena such as La Nina. For example, La Nina brings above normal rainfall to much of Vanuatu, causing flooding, water-logged soils, washed out market roads and additional pests and diseases to crops. Radar can assist in predicting and identifying localised conditions and preparing farmers for threats by – for instance – being protected from the potential impacts of increased heavy rainfall events by raising seed trays, elevating plant beds and establishing off-season coverings and treatment.
- Short term forecasts can enable farmers to adopt appropriate strategies for severe events, such as:
    - Water saving irrigation materials at the prospect of low rainfall or drought.
    - Water harvesting/ storage for later use.
    - Early harvest and storage/ preservation of grains and crops at the prospect of severe storms, floods or drought.

[15] subsistence farming, semi-commercial farming and commercial farming
[16] the last year published data are available

Table 11: GDP for primary industries Vt millions. Source: SPREP, pers. comm., 6 April 2020.

Sector	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Agriculture, Fishing and Forestry:												
• Crop Production	8 180	9 068	10 119	10 183	11 154	13 009	14 201	14 947	15 501	15 428	15 668	17 620
• Animal Production	1 073	1 040	1 309	1 532	1 724	1 928	2 632	2 636	2 952	1 007	1 081	1 091
• Forestry	548	566	613	703	758	798	794	877	979	940	984	1 030
• Fishing	399	413	399	449	439	482	488	485	501	513	527	537
Total Agriculture, Fishing and Forestry	10 201	11 087	12 440	12 868	14 075	16 216	18 115	18 945	19 932	17 888	18 260	20 278
Industry	3 935	4 205	5 453	7 082	8 364	6 887	5 455	5 962	6 429	8 899	9 141	9 650
Services	30 848	33 837	37 971	39 886	41 686	43 803	44 291	46 045	47 889	50 741	54 724	57 745
TOTAL Gross Domestic Product	**48 613**	**53 926**	**61 607**	**65 119**	**67 912**	**70 873**	**72 415**	**75 803**	**79 109**	**82 798**	**87 250**	**94 887**

The Department of Agriculture and Rural Development (DARD) (pers. comm., May 2020) advise that the sector has applied climate information and services for better planning and extension services for some years, starting with the signing of an agreement between DARD, the VMGD, the German Corporation for International Cooperation GIZ and the Vanuatu Agriculture Research and Training Centre, for information sharing and networking. Other activities including the use of climate data for agriculture include *EUARD – the European Union Agriculture Research Development* project which provided training on capacity building for officers in climate modelling and research for development related to use of climate information. This project also included the procurement of three electronic rain gauges that were installed in the main agriculture production areas in Vanuatu so that rainfall data collected could be utilized by the VMGD and analysed for better planning to increase production. The project also included the development of information materials, one notably the ENSO handbook that outlined for every hazard what one should do before, during and after a disaster.

In spite of this, the project document for the project (Global Environment Facility 2016) identifies a number of climate information needs for the agricultural sector including:

- Tailored information on rainfall and drought on daily/ seasonal/ longer term basis linked with early warning systems for management actions and decision-making.
- Comprehensive weather data collection climate information to support crop modelling and seasonal planning.
- Downscaled modelling to support livestock (including bees for the production of honey) management and movements within and across islands as well as to inform agro-forestry animal husbandry priorities and planning.

Personal communication with DARD suggests that a new radar would contribute substantially to addressing these needs.

DARD are particularly concerned to apply climate data to address events such as El Nino and El Nina which severely impact agricultural production. These phenomena are of long duration (several months to a year or more). A new radar service is likely to make the greatest contribution to the forecasting of sudden onset events within them – such as by improved forecasting of convective storms. In the occurrence of such an extreme event, DARD state that improved weather warnings from radar would enable them to provide advice to farmers about protecting produce.

Different assessments of the potential value of radar information in the agricultural sector were applied:

- The average annual costs to agricultural sub-sectors without radar was estimated through reference to reported damage costs. Avoidable damage functions were applied from Subbiah et al. (2008) and DARD. These were used to estimate average annual damage costs across all probable tropical cyclones.
- Average annual costs to agriculture over all probable tropical cyclone events was taken from PCRAFI and used to illustrate potential overall savings using damage functions from Subbiah et al. (2008), DARD and a hypothetical reduction in damage of one tenth of one per cent (0.001) could be secured.

5.1 Agricultural costs associated with TC Pam and TC Harold

Esler (2015) reports the estimated costs of TC Pam to the crops and livestock sectors to be in the order of Vt 4.7 billion, of which Vt 0.4 billion was the result of damage (such as harm to land, irrigation/drainage systems, storage facilities and stored inputs/goods, machinery) and Vt 4.3 billion was the result of losses (e.g., crop losses, reductions in yield, higher costs). Costs estimated include impacts on the subsistence sector as well as commercial sectors (Dominique Blariaux, FAO, pers. comm., 15 April 2020). Assuming that TC Pam is a 1:500-year event (PCRAFI 2015), average annual damage costs for crops and livestock are presented in Table 12.

Leo (2020) reports that the expected repair and replacement costs associated with agricultural damage from TC Harold to be in the vicinity of Vt 632 million (Table 13). Bearing in mind that no loss data was included in this assessment, these costs from the event are an underestimate.

Table 12: Average annual crop and livestock damage costs for TC Pam Vt. Source: Esler (2015).

Sector	Average annual damage costs	Average annual loss costs
Crops	263 192	8 086 556
Livestock	565 504	526 266
Total	**828 696**	**8 612 822**

Table 13: Agriculture damage costs for TC Harold Vt. Source: Leo (2020).

Reported treatment costs	Total	Average
Immediate response and recovery	546 060 000	
Medium to long term response	86 900 000	
Total	**632 960 000**	**1 265 920**

5.1.1 Potential damage savings based on Subbiah et al. (2008)

Based on assumptions by Subbiah et al. (2008) that early warnings can reduce damage to livestock by 10-45 per cent and damage to agriculture by 10-70 per cent, early warnings from radar could result in average annual damage savings in crops and livestock:

- For a TC Pam-type event in the order of between Vt 83-310k (Table 14).
- For a TC Harold-type event in the order of between Vt 127-570k (Table 15). In this case, the breakdown between crops and livestock was not given so the more conservative saving rate applying to livestock was applied to total values to estimate minimum savings.

Table 14: Indicative potential annual damage savings in TC Pam agricultural from early warnings Vt.

Sector	24-hour warning	48 – hour warning	Up to 7 days
Crops	26 400 pa	79 200 pa	55 440 pa
Livestock	56 600 pa	226 400 pa	254 700 pa
Total	**83 000**	**305 600**	**310 140**

Table 15: Indicative potential annual savings in TC Harold agriculture damage from early warnings Vt.

	24-hour warning	48 – hour warning	Up to 7 days
Crops and livestock	126 592	506 368	569 664

5.1.2 Potential damage savings based on DARD estimates

DARD (pers. comm., 14 May 2020) state that farmers are accustomed to preparing for disasters and responding to warnings. They suggest that short warning times for major events provide limited opportunity for farmers to avoid costs but that longer lead times enable them to advise farmers to trim crops, and or harvest and store mature food, and or provide support structures for green houses and nurseries. Nevertheless a radar would increase warning ability for localised storms as well as increase the accuracy of forecasts for bigger events.

5.1.3 Losses

No dedicated functions are provided by Subbiah et al. (2008) of potentially avoidable crop and livestock losses – such as increased operating expenses – from early warnings. Similarly, responses from DARD focused on avoidable damage. Nevertheless, the protection of physical assets through improved preparation can be expected to directly reduce losses in the agricultural sector (e.g., increased costs and reduced yields). As an indication of the order of magnitude, a 1 per cent reduction in average annual losses in crops and livestock from improved warnings would generate national cash savings for a TC Pam-type event in the order of Vt 86128 per year (1 per cent of the Vt 8,612,822 noted in Table 16).

Assuming that the proportion of (reported) damage to (unreported) losses remained the same in TC Harold as it was in TC Pam, the potential losses from TC Harold could be in the order of Vt 6.6 billion[17], generating average annual losses of around Vt 13 million (Table 16). A reduction of even one per cent (0.01) in average annual losses from improved warnings[18] would generate national cash savings per year for a TC Harold-type event in the order of Vt 131,195. These values are only indicative.

Table 16: Indicative potential savings from agricultural losses Vt.

Cost	Reported damage	Reported loss	Estimated loss	Estimated average annual loss	1% loss reduction pa
TC Pam crop costs	131 596 000	4 043 278 000			
TC Pam livestock costs	282 752 000	263 133 000			
Total TC Pam crop and livestock costs	**414 348 000**	**4 306 411 000**		8 612 822	86 128
Damage and loss as % of total costs	8.8	91.2			
TC Harold crop costs	632 960 000		6 559 767 273	13 119 535	131 195

In each case, 25 per cent of savings would be manifest through the commercial sector and 75 per cent would be manifest through protection of subsistence production, contributing to family and national food security.

[17] If Vt 1632.96 million represents 8.8 % of total damage costs, 100% of total costs would equal Vt 932.96 million/ 0.0088 – Vt 7.1 billion. The 91.2% loss component would be worth Vt 6.56 billion. This represents an annual average loss for TC Harold of Vt 13.1 million.

[18] Arising from the ability to protect assets

5.2 Illustrative benefits PCRAFI

PCRAFI estimate the national value of major cash crops in Vanuatu to be in the order of USD 420 million. Based on this and previous climate related events, the average annual replacement cost of crop damage across Vanuatu is modelled under PCRAFI to be USD 1.4 million (Table 17). The value of damage to crops is modelled to increase as the severity of the event increases. For example, a hazard event with a return frequency of 10 years is modelled to generate average crop costs of USD 3.9 million, while an event with a return frequency of 100 years is modelled to generate average annual costs of USD$ 14.6 million (Table 17).

As an indication of the potential scale of savings with early warnings, if annual average damage from climatic events were reduced by even a tenth of one per cent (0.001), savings to average annual crop losses in Vanuatu would be in the order of USD 1,429 per year[19]. However, the cost data reported for PCRAFI is based on asset data secured over 2006-2009. Taking 2009 as the base year, the US dollar purchased approximately Vt 122.07 in 2009 (LikeForex 2020), implying annual average crop losses today worth around Vt 174,438.03 in Vanuatu. Since this time, the purchasing power of the Vatu has changed. Based on historical CPI data of the Vatu (knoema 2020 and Tradingeconomics 2020), this annual average saving would be worth approximately Vt 209,221 per year.

If the proportion of possible annual savings was increased to reflect DARD estimates of 50 per cent possible damage savings or Subbiah et al. (2008) estimates, possible annual savings to crops alone would be between Vt 0.1-1 million per year (Table 18).

[19] USD 1 428 809 x 0.001.

Table 17: Modelled replacement costs of major cash crops in Vanuatu. Source: PCRAFI

Province	Average annual loss	2	5	10	20	40	50	65	90	99	Total exposure Value
Torba	0	0	0	0	0	0	0	0	0	0	3 763 680
Sanma	281 303	8 346 530		6 008 330	4 747 070	3 577 910	3 147 570	2 665 260	1 520 880	752 667	45 855 720
Penama	618	14 770	12 704	10 721	9 156	6 760	6 017	5 050	2 834	1 563	1 335 000
Malampa	75 938	1 674 780	1 577 480	1 292 520	1 015 870	835 790	741 312	644 707	415 413	283 724	79 972 500
Shefa	892 667	20 650 300	17 173 200	14 686 000	11 443 200	8 689 430	7 201 260	6 202 420	3 956 660	2 347 950	207 216 600
Tafea	178 283	2 733 380	2 454 980	2 121 420	1 792 760	1 527 210	1 384 250	1 182 220	814 223	519 423	81 874 280
Total	**1 428 809**	**33 419 760**	**2 121 8364**	**24 118 991**	**19 008 056**	**14 637 100**	**12 480 409**	**10 699 657**	**6 710 010**	**3 905 327**	**420 017 780**

*Probability of exceedance. There is a:

2 2% probability that this value will be exceeded in 50 years (2475-year event)
5 5% probability that this value will be exceeded in 50 years (975-year event)
10 10% probability that this value will be exceeded in 50 years (475-year event)
20 20% probability that this value will be exceeded in 50 years (224-year event)
40 40% probability that this value will be exceeded in 50 years (100-year event)
50 50% probability that this value will be exceeded in 50 years (72-year event)
65 65% probability that this value will be exceeded in 50 years (50-year event)
90 90% probability that this value will be exceeded in 50 years (22-year event)
99 99% probability that this value will be exceeded in 50 years (10-year event)

Table 18: Indicative potential annual crop damage savings based on PCRAFI AAL estimates Vt.

	DARD	Subbiah et al. (2008)		
	Up to 7 days	24 hr	48 hr	Up to 7 days
Potential % damage avoided	50	10	30	70
Potential PCRAFI saving	714 405	142 881	428 643	1 000 166

6 Fisheries sector

According to Global Environment Facility (2016) 72 per cent of the households possess fishing gear and engage in fishing activities. It is estimated that there are around 4000 fishing boats, of which 3,500 are canoes taking on average 2.83 fishing trips per week, providing nutrition for around 60 per cent of the population.

The Department of Fisheries already use climate and weather information in Vanuatu to inform fishing trip plans, drawing on information such as sea surface temperature and ocean acidification (accessed via the Ocean Portal). While this information meets most meteorological needs for planning (Department of Fisheries, pers. comm., 15 May 2020), there can be challenges. The Department notes that some forecasts give false information, which can lead to poor planning. They consider that false readings may be the result of insufficient or inadequate tools to support site-specific monitoring such as ocean buoys (Department of Fisheries, pers. comm., 15 May 2020). The introduction of radar would assist in these matters by enhancing localised forecasting.

The proposal for the Van-KIRAP project (Global Environment Facility 2016) indicates a number of climate information needs for fisheries including:

- Site specific forecasts.
- Improved access and ability to apply climate data and information is required, and improved technology is needed to support a marine climate early warning system for Vanuatu.

Assessments of the potential value of radar information in the fishery sector were conducted by applying estimated annual costs from TC Pam without radar to avoidable damage functions from Subbiah et al. (2008) and the Department of Fisheries. These indicate potential savings from one major event type only.

The Vanuatu Department of Fisheries (pers. comm., 15 May 2020) consider that radar information would considerably address these issues. They view that the addition of radar would enhance site specific forecasting and early warnings, better enabling fishers to prepare for extreme events and increasing their ability to avoid damage and better preserve their ability to harvest fish. The latter benefit arises with the increased ability of fishers to prepare for extreme events and avert damage to equipment. For example, presently, some fishers operate in remote areas without network coverage, with warnings only transmitted by word of mouth. The longer the lead time for localised warnings, the greater the chances are that operators in remote areas will receive warnings and avoid damage to equipment (e.g., storing equipment or reconsidering fishing trips altogether where rough waters would reduce catches or risk safety). Additionally, greater lead times for severe local events enables operators to ensure that they secure sufficient fuel to resume fishing rapidly after an event. In this way, commercial earnings and local food supplies can recover faster.

According to the Department of Fisheries, the longer the lead time for an extreme weather event, the greater the proportion of costs that fishers can save. To this end, the Department of Fisheries considers that warnings can reduce damage an average of 25 per cent with the spread of possible savings ranging from 20-80 per cent (Table 19).

Table 19: % Potential fisheries damage avoided with improved warnings. Source: Department of Fisheries, pers. comm., 15 May 2020).

	Probable % avoidable damage costs
6 hours	20
24 hours	50
72 hours	80
Average estimated	25

According to Esler (2015), the total estimated costs to the fishery sector of TC Pam were Vt 391 million, of which two thirds (VT 268 million) constituted damage (Table 20). Damage in the fisheries subsector includes the destruction of fisheries infrastructure and the loss of fishing equipment, canoes, and a few boats. Half of the damage affected artisanal (small scale, traditional or household) fishery activities, and the other half was distributed between commercial fisheries (24 per cent) and loss of fisheries infrastructure (17 per cent).

Assuming that TC Pam is a 1:500-year event (PCRAFI 2015), average annual damage costs to the fishery sector are estimated to be Vt 536 506 to Vanuatu (damage divided by 500 years – Table 20).

Table 20: TC Pam fisheries damage Vt. Source: Esler (2015).

Cost	Reported damage	Reported loss	Total cost
Fishery costs*	268 253 000	122 486 000	390 739 000
Annual costs	536 506	244 972	781 478
% of total	69	31	100

With an average annual damage cost from TC Pam of Vt 536,506, potential benefits of new warnings arising from radar would vary from Vt 0.1-0.4 million per year, depending on whether avoidable damage functions from Subbiah et al. (2008) or the Department itself are applied (Table 21).

Table 21: Indicative potential annual fisheries savings from TC Pam Vt.

New warning length:	6 hours	24 hours	72 hours	Average
Subbiah et al. potential damage savings on TC Pam	53 651	80 476	>80 476	
Fisheries department potential damage savings on TC Pam	107 301	268 253	429 205	134 127

In the case of TC Harold, preliminary assessments by DARD suggest that the costs arising from the cyclone include damage to craft and equipment (boats, canoes, fishing gear, outboard engines, safety gear, freezers, fish aggregation devices etc.,) as well as lost income arising from inability to operate as usual. Preliminary assessments indicate that the total estimated costs to the fishery sector of TC Harold were Vt 1.6 billion, of which two thirds (VT 1.2 billion) constituted loss costs (Table 22). Assuming that TC Harold is a 1:500-year event, average annual damage costs to the fishery sector are around Vt 611k to Vanuatu (Table 22).

Table 22: TC Harold fisheries costs Vt. Department of Fisheries (2020).

Cost	Reported damage	Reported loss	Total cost
Reported costs	305 371 149	623 783 993	929 155 142
Annual costs	610 742	1 247 568	1 858 310
% of total	33	67	100

Based on these average annual damage costs, potential benefits of new warning systems arising from radar would vary from Vt 0.1-0.5 million per year, depending on whether avoidable damage functions from Subbiah et al. (2008) or the Department itself are applied (Table 23).

Table 23: Indicative potential annual fisheries savings from TC Harold Vt

New warning length:	6 hours	24 hours	72 hours	Average
Subbiah et al. potential damage savings on TC Harold	61 074	91 611	>91 611	
Fisheries dept potential damage savings on TC Harold	122 148	305 371	488 594	152 686

7 Tourism sector

Tourism forms a key component of the ni-Vanuatu economy. Esler (2015) notes that tourism expenditure as a percentage of GDP increased from 26 per cent in 2002 to 33 per cent in 2010 and accounted for up to 4,000 direct jobs.

Hydrometeorological events can severely harm tourism earnings. TC Pam was reported to generate damage varying from minor repairs to major structural damage to buildings, facilities, and land. This in turn resulted in closures while operators repaired damage and consequently lost business (Esler 2015). As a result, TC Pam was estimated to incur around VT 5.9 billion in damage and VT 3.6 billion in losses (Esler 2015). Tourism costs were estimated to account for 20 per cent of total costs of the cyclone (Table 24).

Table 24: Tourism costs from TC Pam.

Province	Damage	Losses	Total Effects
Malampa	1 000	8 630	9 630
Penama	4 000	20 000	24 000
Shefa	5 775 898	3 455 426	9 231 324
Tafea	127 333	31 982	159 315
Sanma	N/A	93 563	93 563
Total	5 908 231	3 609 601	9 517 832

The Ministry of Infrastructure and Public Utilities (pers. comm., May 2020) consider that a new radar system would benefit tourism by increasing the safety of aviation and boating upon which tourism transport relies: the new radar would improve the ability to track and forecast small scale convective (thunderstorm) events which are important for the safety of craft – especially smaller aircraft – in terms of threats such as turbulence, hail, icing and down drafts on landing.

Views from the Ministry of Trade, Commerce, Industries, Tourism and Cooperatives of Vanuatu, Department of Tourism (DoT) suggest that the introduction of a national radar would improve economic resilience in the tourism sector by enabling better planning. For example, radar information can assist in the refinement of provincial calendars (e.g., to time cultural events to coincide with weather), improve scheduling of tours to avoid localised events and to enable operators to thereby avoid unnecessary spending on materials (Ministry of Trade, Commerce, Industries, Tourism and Cooperatives of Vanuatu, Department of Tourism, pers. comm., June 2020). With improved shorter-term localised information, operators can better plan alternatives. For instance, tour operators can advise clients of potential changes to suit the weather and provide options to avoid last minute cancelations and refunds on prepaid tours. For sudden severe weather events, radar information would enable operators to more rapidly prepare to store equipment and assets for protection, protect guests and organise provisions as needed.

In light of these opportunities, the Ministry considers that the costs to the tourism sector from improved warnings could be as much as halved with improved warnings. This would represent indicative potential damage savings for a TC Pam-sized event in the order of Vt 10 billion. However, asset protection is likely to remain practical only for moveable or smaller assets and major structural damage to buildings, facilities, and land caused by severe events would remain unavoidable, regardless of radar-improved warnings. For this reason, illustrative savings of 25 per cent of damage are used to consider the potential value to the tourism sector of a new radar system.

8 Infrastructure sector

8.1 Public works

Ministry of Infrastructure and Public Utilities (MIPU) (pers. comm., 15 May 2020) considers that radar services would enable alerts and flood warnings from rainfall intensity monitoring to support the Public Works Department. For example, new alerts and warnings would assist in planning weather-impacted activities; civil works could be postponed within 6hrs to 12 hours, therefore saving resources.

According to the Public Works Department budget for 2019, the annual assignment for infrastructure repairs for Vanuatu was in the order of Vt 1.36 billion (Table 25). Assuming an average number of public service working days of 250 per year[20], this implies an average cost assignment of Vt 5,451,447 for public works per day. These works would need to be planned, with staff and supplies assigned to days or weeks. However, sudden changes in weather could impact the delivery of repair work.

Table 25: 2019 Annual Public Works Department Vt. Source: Public Works Department (2019).

	Routine maintenance	Periodic maintenance	Improvement works	Stockpiling	Supply of materials	Total
Vt	152 916 789	132 235 410	953 120 951	84 588 709	40 000 002	1 362 861 861

Weather Radar would enable forecasts of sudden changes in local weather in a short range of time and enable Public Works to reschedule and relocate planned actions. At present, the number of days that Public Works' planned activities are obstructed due to poor weather are not known. An indication of potential savings using weather radar can be made, however. For example, if it is assumed that weather radar is available for better planning of works and that this allowed the Public Works Department to recoup five days of work per year, this would generate cash savings to the ministry of Vt 5.45 million per year.

In addition, improved weather data from radar would be expected to enable better engineering design for infrastructure such as bridges, roading and or drainage, leading to reduced damage and loss from hydrometeorological events and an associated reduced need for repair.

[20] 5 days x 50 weeks (52 annual weeks less 2 weeks' worth of public holidays)

9 Aviation sector

Estimation of potential savings from radar was based on the views of the aviation sector for how improved data could improve warnings.

Hydrometeorological events can cause significant damage to aviation infrastructure and impact earnings through flight disruption and safety threats. Weather related events of concern to Vanuatu's Civil Aviation Authority (CAA) are:

- Tropical cyclones which can cause damage to airport infrastructure e.g., terminals.
- Heavy rainfall which can burst riverbanks and harm aerodromes close by.
- Storm surge from cyclones which can inundate airstrips (CAA, pers. comm., 19 May 2020).
- Ashfall which can interfere with instrumentation and engines.

Examples of extreme events affecting the aviation sector in the last 20 years include:

Air crashes

- 5 May 1999: a Twin Otter aircraft took off from the island of Espiritu Santo in driving rain and crashed while making a landing approach at Port Vila's Bauerfield Airport. Five people died (Pacific Islands Report 1999).
- 19 December 2008: an Air Vanuatu Britten-Norman Islander aircraft (Flight NF 261) crashed into a mountain on the western side of the island of Espiritu Santo, Vanuatu killing the pilot and seriously injuring some passengers (Shine Lawyers 2020).
- 2 August 2011: a Cessna 207 crash-landed at the Warwick Le Lagon Resort amid heavy rain and thick fog which meant that the pilot had difficulty locating the runway (RNZ 2011).

The CAA use weather information daily to inform flight safety as well as prepare to protect infrastructure from severe events such as cyclones.

Radar data can enhance understanding of near or present weather threats by – for instance – incoming hailstorm, wind surge, severe thunderstorms and indicating whether flooding is eminent within an airport within 6 to 24 hours (Ports and Marine Department, pers. comm., 15 May 2020).

Warnings can reduce damage to the aviation sector to different extents, depending on the length of lead-in time. For example, with imminent warnings, staff can cover up to protect workspaces and computers, store basic equipment and redirect flights while, with longer warnings, more protective measures can be undertaken, such as the reinforcement of footing or buildings to withstand strong winds. The longer the lead in time, the greater the extent of damage avoidable. CAA estimate that damage to infrastructure through warnings can enable a reduction in damage costs of between 10-75 per cent (Table 26).

Table 26: Avoidable damage rates for the aviation Sector %. Source: CAA (pers. comm., 19 May 2020)**.**

Warning time	Expert 1: potential savings	Expert 2: potential savings
6-hour warning	20%	10-20%
24-hour warning	30%	50%
72-hour warning	50%	75%

A key issue for the CAA is the need to improve weather forecast accuracy, which they presently rate to have a 50 per cent success rate. Weather information is critical to plan flight operations and inaccurate warnings can harm company's operations such that incomes (flights) can be damaged.

Documentation on the cost of air crashes related to extreme weather is presently not available for the purpose of this assessment. However, data does exist on the cost to infrastructure on which the aviation sector relies. Esler (2015), for example, estimates the costs of damage to the aviation sector in TC Pam as approximately Vt 3 billion, of which aviation constituted 20 per cent (Table 27).

Table 27: TC Pam Damage and Loss Summary for Transport Sector Vt. Source: Esler (2015)**.**

Sector	Damage	Losses	Total
Roads and Bridges	2 358 718 000	84 988 000	2 443 706 000
Aviation	617 103 000	905 315 000	1 522 418 000
Maritime	41 600 000	1 147 046 000	1 188 646 000
Total	**3 017 421 000**	**2 137 349 000**	**5 154 770 000**

Based on the averages of these rates, a new warning for aviation could reduce damage costs from a TC Pam-type event in the order of Vt 0.2-0.8 million per year (Table 28).

Table 28: Indicative potential avoidable damage for the aviation sector for TC Pam.

Sector	6 hours	24 hours	72 hours
Aviation	10-20	30-50	50-75
Average annual potential damage savings TC Pam	215 986	493 682	771 379

10 Water and sanitation

Estimation of potential savings from radar was based on the views of the Department of Water Resources (DWR) for how improved data could improve warnings. The DWR (pers. comm., 18 May 2020) already apply weather and climate information in their planning. Weather forecasts and warnings are incorporated to the engineering designs for water harvesting systems, hydrological monitoring for flash floods and hydroelectricity monitoring.

The biggest weather events of concern to the DWR are severe tropical cyclones and ENSO events. While ENSO events have limited impact on physical infrastructure, they affect water supply. Tropical cyclones can cause considerable harm to water infrastructure and, in turn, result in water shortage and water quality problems (DWR pers. comm., 18 May 2020).

In the case of TC Pam, damage to the water, sanitation and solid waste sectors included harm to sanitation structures made from bush materials as well as to water and sanitation facilities at education and health centres (Esler 2015). In the case of TC Hola, damage reflected harm to water systems such as broken water pipes, loss of rooves (which operate as water catchments) and contamination of water tanks and ground wells as a result of debris (Government of Vanuatu 2018b). Reported costs[21] for the two events are provided in Table 29.

Table 29: TC Pam and TC Hola water and sanitation damage.

Cost item	Damage	Losses	Total	Source
Total cost TC Pam	413 555 000	283 712 000	697 267 000	Esler (2015)
Annual cost	827 110	567 424	1 394 534	Calculation
Total repairs/replacement TC Hola	46 608 780	[not available]		Government of Vanuatu (2018b)
Annual cost	621 450			Calculation

Early warnings, such as those possible using weather radar data, can enable water planners and users to better prepare for weather risks and disaster events. The DWR (pers. comm., 18 May 2020) advise that short term (e.g., 6 hour) warnings enable immediate actions such as water storage and disconnection of small scale water systems to take place, while longer lead time (say 24-72 hours) can enable more extensive preparation for serious events, such as securing water infrastructure, disconnecting high risk areas and the preparation of emergency supplies and storage facilities for emergency. The DWR suggest that – depending on the degree of lead time provided – savings of up to 25-80 per cent of damage costs from a cyclone, with an average potential saving of 35-49 per cent, providing that communities respond to the warnings also (Table 30).

Table 30: Avoidable damage rates for the water and sanitation sector TC Pam.

Sector	6 hours	24 hours	72 hours	Average
Potential damage savings %	<25	≤50	75 – 80	35-49

Based on the averages of these rates, a new warning for the water and sanitation sector could reduce damage costs from a TC Pam-type event by around Vt 0.1-0.6 million per year – or an average expected saving of Vt 0.3 million per year (Table 31).

[21] PNA damage and loss for TC Pam; replacement and repair of damage for TC Hola

Table 31: Indicative potential water and sanitation damage savings for TC Pam Vt.

Sector	6 hours	24 hours	72 hours	Average
Potential savings	124 067	206 778	620 333	347 386

Due to different reporting content, it was not possible to draw a relationship from the average annual damage costs of TC Pam and TC Hola.

11 Buildings

SPC estimates that the national value of building assets in Vanuatu to be around USD 2.86 billion (Table 32). Based on this and previous climate related events, the average annual replacement cost of building damage across Vanuatu is modelled to be USD 24.6 million (Table 32). The value of damage to buildings is modelled to increase as the severity of the event increases. For example, a hazard event with a return frequency of 10 years is modelled to generate average building costs of USD 54.5 million, while an event with a return frequency of 100 years is modelled to generate average annual costs of USD 392 million. These values are 2009 values.

As a general observation, warnings provide limited scope to protect buildings from natural hazards, although some measures may be taken to reduce damage, such as boarding up windows and securing rooves to reduce storm or ash damage.

Converting average annual costs of building damage to Vatu today[22], the average annual cost of damage from tropical cyclones to buildings in Vanuatu is approximately Vt 20.5 million. As an indication of the potential value of radar-improved warnings to the building sector, if annual average damage from climatic events were reduced by even a tenth of one per cent (0.001) savings to Vanuatu this would be worth around Vt 20,490 per year in present day terms.

In the case of TC Pam, Table 5 indicates that damage to private housing was in the order of Vt 9.45 billion – an average cost of Vt 18.9 million per year. A reduction of one tenth of one per cent of this value would indicate an annual saving in building damage of Vt 18,904 (Table 33).

[22] Converted from USD dollar exchange rates in 2009 (LikeForex 2020) and updated to 2019 values using CPI data of the Vatu (knoema 2020 and Tradingeconomics 2020).

Table 32: Modelled average annual building costs USD$ from hazards by Vanuatu province. Source: PCRAFI model, Litea Biukoto, Manager Disaster Reduction Programme, SPC, pers. comm., 21 April 2020**.**

		Probability of exceedance*								
Province	**AAL**	**exceed_2**	**exceed_5**	**exceed_10**	**exceed_20**	**exceed_40**	**exceed_50**	**exceed_65**	**exceed_90**	**exceed_99**
Torba	555 837	15 830 573	13 312 541	10 763 282	8 672 744	6 412 196	566 3040	4796626	2 653 880	1 321 316
Sanma	6 224 075	207 040 980	162 468 240	145 433 910	124 121 530	93 629 316	78 589 531	64748154	31 432 088	13 818 904
Penama	3 315 016	83 089 436	78 538 170	70 308 878	60 146 072	47 559 452	41 686 841	33620833	17 873 287	8 058 618
Malampa	3 709 360	103 250 580	95 674 554	78 233 365	65 081 594	49 040 393	43 283 860	37143803	20 046 238	8 804 135
Shefa	9 122 198	436 940 320	375 234 630	299 601 180	237 790 690	165 089 060	130 045 010	95986266	42 924 977	19 245 929
Tafea	1 649 313	70 244 409	58 731 771	50 801 809	40 709 306	30 730 088	25 773 713	19125113	8 163 264	3 272 104
Total	**24 575 799**	**916 396 298**	**783 959 906**	**655 142 424**	**536 521 936**	**392 460 505**	**325 041 995**	**255420795**	**123 093 734**	**54 521 006**

*Probability of exceedance. There is a:

2 2% probability that this value will be exceeded in 50 years (2475-year event)
5 5% probability that this value will be exceeded in 50 years (975-year event)
10 10% probability that this value will be exceeded in 50 years (475-year event)
20 20% probability that this value will be exceeded in 50 years (224-year event)
40 40% probability that this value will be exceeded in 50 years (100-year event)
50 50% probability that this value will be exceeded in 50 years (72-year event)
65 65% probability that this value will be exceeded in 50 years (50-year event)
90 90% probability that this value will be exceeded in 50 years (22-year event)
99 99% probability that this value will be exceeded in 50 years (10-year event)

Table 33: Damage and loss in the housing sector (TC Pam) Vt.

Cost	Damage	Losses	Total Effects
Reported TC Pam cost	9 452 175 000	440 490 000	9 892 665 000
Average cost per year	18 904 350		
Reduction by 0.001	18 904		

12 Safety and lives

In addition to the avoidance of damage and loss to sectors, improved weather information can improve safety. As an example, the Department of Ports and Harbour (pers. comm., 14 May 2020) observes that – although Vanuatu provides general cyclone warnings to our local ships – there is no radar system to advise sea farers of local or flagged ships of warnings. Only general weather information on ocean waves, winds and rough seas in Vanuatu's waters is presently available for local and international shipping. With the introduction of radar, the Ports and Marine Department (Ports and Marine Department, pers. comm., 14 May 2020) consider that the scale and observation on ocean waves, winds and rough seas will be more downscaled weather information around each island.

A new radar for Vanuatu could also improve aviation safety (CAA, MIPU and the Ports and Marine Department). Nowcasting products possible from radar would theoretically enable more accurate time range forecasts. This would enable flight rescheduling or cancellation to improve flight safety, while warnings such as aerodrome warnings (e.g., search and rescue, emergency landing) could be issued with more certainty and accuracy. At the moment, aviation forecasts rely heavily on satellite imagery that is updated every 10 minutes (MIPU and Ports and Marine Department, pers. comm., 14 May 20520).

12.1 Human losses

Estimation of potential human losses avoided follows Hallegatte (2012) who demonstrates that average probability of weather-related fatalities across the developed world is in the order 2.2 lives lost per million, compared with a probable fatality rate in the developing world of 7.5 lives per million. Hallegatte (2012) observes that this difference is due to a variety of factors, including housing and infrastructure quality, disaster protection, evacuation procedures as well as early warnings. He assumes that generalizing the early warning and evacuation systems available in developed countries would make the death probability decrease from 7.5 per million to 4 per million (approximately a 50 per cent reduction).

As noted in Section 2.1, extreme weather events killed an average of 2.27 persons per year in the last 30 years. With a population of approximately 272,459 (Vanuatu National Statistics Office 2013), this is a probable fatality rate of 8.2 per million, consistent with Hallegatte's estimates.

Following Hallegatte (2012), if improved radar capability in Vanuatu reduced the death probability from 8.2 per million to 4 per million – so that it is still twice that of the developed world – deaths per annum would fall around 52 per cent to around 1.18 per year. This is a reduction of just over one life lost per year on average for Vanuatu.

12.2 Value of productivity lost as a result of death

As indicated in Section 2, the population of Vanuatu is presently assumed as 272,459 (Vanuatu National Statistics Office 2013). The average life span in Vanuatu is 70 for men and 74 years for women (World Life Expectancy.com Undated). Basic education in Vanuatu starts at the age of 7 and is compulsory for 6 years until the age of 12 (see JICA Undated). Theoretically children are expected to benefit from 11 years of schooling, although UNDP (2019) observe that in Vanuatu the average child only stays for the 6 compulsory years, suggesting an average start to employment of 12 years. With retirement age at 55, the average expected working life in Vanuatu is 43 years. While unemployment has averaged around 6 per cent over the last three decades (see the Global Economy) and rarely drops below five per cent, formal employment is not extensive. Only 20 per cent of the workforce is engaged in formal sector employment (ILO Undated). The majority of the population make their living through small scale and or subsistence agriculture.

The minimum wage in Vanuatu was increased by the government in September 2019 from Vt 200 per hour to Vt 220 per hour (Massing 2019). If a paid 37.5-hour week is followed, this implies an annual salary of around Vt 429,000 per year, or approximately USD 43,759[23]. This value differs from surveys of salaries conducted by Average Salary Survey.com (2020) which states that the average salary in Vanuatu is Vt 2,962,412 (gross) – around USD 25,954 per annum.

An average working life of 40 years is assumed. People affected by severe weather events may be at the start of their lives, facing a full working life (e.g., babies and children), at the end (retired) or part way through. An average lost working life of 20 years is therefore assumed per life lost as a result of severe weather events.

Based on an average loss of 20 years' production and an average salary of USD 26-43k (see above), one life saved per year as a result of radar-enabled early warnings represents a production saving of USD 1.2-2.0 million (2.27 people x 20 years x USD 26k or USD 43k) (Table 34). The average value per year of Vt 1,582,489.64 is used.

Table 34: Estimated earning losses from lost lives Vt.

	Vt
Average salary per year	25 954 – 43 759
Average fatalities per year	2.27
Average salary lost per year	58 916 – 99 332
Loss of salaries over 20 years	1 178 320 – 1 986 658

[23] https://www1.oanda.com/currency/converter/, accessed 30 March 2020.

13 Personal possessions

In receiving and acting on warnings for extreme weather events, improved warnings can be expected to not only protect lives but also enable affected people to protect some basic (e.g., moveable) possessions.

Esler (2016) states that the estimated cost of damage to household goods in the TC Pam post disaster needs assessment was 5 per cent of total housing costs (damage and loss combined). Given that the total damage and loss to housing of TC Pam was Vt 9.9 billion, the estimated cost of personal possessions would be in the order of Vt 495 million so the average cost per year would be around Vt 0.99 million (Table 35).

Table 35: Damage to housing and personal possessions – TC Pam Vt.

	Vt	Source
Total cost to housing	9 892 665 000	Esler (2016)
5% for personal possessions lost	494 633 250	Estimation
Annual cost	989 267	

Based on assumptions by Subbiah et al. (2008) that early warnings can reduce damage to household items by between 20 and 90 per cent (Table 9), early warnings from radar could result in annual damage savings of Vt 198-890k (Table 36). If the rates developed by Day (1970) are considered, the range varies from Vt 297-346k per year for new warnings of 24-48 hours.

Table 36: Potential annual avoidable damage to personal possessions Vt.

Lead time	Potential savings in household possession costs Vt (Subbiah et al.)	Potential savings in household possession costs Vt (Day 1970)
24 h	197 853	296 780
48 h	791 413	346 243
Up to 7 days	890 340	Not available

These values presume that 100 per cent of people in a flood zone area receive the warning on time and then act accordingly. This may not be the case in practice. Where floods occur at night, warnings are more difficult to pass on (people asleep, televisions and radios switched off etc.,) and, in any event, not all members of the public act when a flood occurs. As an example, a survey of Fiji's Nadi community flooded in 2009 reveals that 19 per cent of community members interviewed did not take action to minimise flood damage once they became aware of the oncoming flood (Holland 2009).

14 Summary of quantitative sectoral findings

Based on the discussion above, potential savings to Vanuatu of radar operation were quantified for the following sectors:

- Agriculture.
- Fisheries.
- Aviation.
- Tourism.
- Water.
- Production value of lives lost.
- Building damage.
- Personal possessions.

Alternative calculation methods could have been applied for some of these sectors. Of these, values selected to calculate potential payoffs of radar investments over time were as follows:

- Where estimated, values are selected if they are based on relationships for all probable tropical cyclones and founded on previous events (e.g., PCRAFI data).
- Potential savings increase with longer lead times. In the interest of being conservative, the values from introducing new 24-hour warnings are selected.
- Lower estimated values are selected where more than one value exists (e.g., value of warnings to protect personal possessions as calculated using formulae from Day (1970) and Subbiah et al. (2008)).

Assumed annual savings selected for the cost benefit calculation are summarised in Table 37. As can be seen from Table 37, these estimates are for the most part underestimates due to the lack of data.

Table 37: Assumed annual savings per sector from new radar-supported warnings.

Cost type	TC Pam only		TC Harold only		Policy dimension
	Vt	Comment	Vt		
Agriculture – avoided damage	82 870	TC Pam – 24-hour warning – annualised savings	126 592	TC Harold – 24-hour warning – annualised savings Does not include losses	Major food security issue
Agriculture – avoided losses@0.01	86 128	Illustrative @0.01	131 195	Illustrative @0.01	Major food security issue
Fisheries – avoided damage	268 253	TC Pam – 24-hour warning – annualised savings	305 371	TC Harold – 24-hour warning – annualised savings	Major food security issue
Tourism – avoided damage	4 758 916	TC Pam - average 25% annualised damage and loss savings	109 403	TC Harold – average 25% annualised damage and loss savings Underestimate as only Sanma province covered and focussed mainly on damage, not future losses	
Public works – road and general maintenance	5 451 447	Illustrative @ 5 days improved planning per year	5 451 447	Illustrative @ 5 days improved planning per year	
Aviation – avoided damage	493 682	TC Pam – 24-hour warning – annualised savings	473 431	TC Harold – 24-hour – annualised savings	Critical to re-establish tourism sector
Water and sanitation – avoided damage	306 031	TC Pam – 24-hour warning – annualised savings	618 149	TC Harold – 24-hour warning – annualised savings	
Buildings – avoided damage	18 904	Illustrative @0.001; private homes only	2 130	Public buildings only Illustrative at 0.001, annualised	
Earnings saved through reduced fatalities	1 582 490	Average last 30 years	1 582 490	Average last 30 years	
Personal possessions – avoided damage	197 853	TC Pam – 24-hour warning – annualised savings		Not available	
Total	**13 246 575**		8 800 207		

14.1 Items not valued

14.1.1 Sectors

Sectors not valued are listed in Table 38. Some of the sectors not valued are likely to benefit significantly from radar. For instance:

- Improved warnings for severe localised events will enable businesses to prepare to protect assets. In 2017, the retail trade alone accounted for 14 per cent of national GDP. Protection of commercial and industrial assets is essential and is likely to be of considerable value. Alerts about severe events including flash floods means that businesses can relocate or elevate moveable equipment and machinery as well as stocks, while farmers can relocate livestock (goats, pigs, chickens and cattle). As part of this, improved warnings for sudden localised events can enable businesses to relocate essential documentation. SOPAC (Holland 2009), for example, notes that the loss of lists of debtors to some businesses as a result of Fiji floods could impede their recovery.
- With improved warning systems, communities may feel more secure and reduce the trauma of losing loved ones or sustaining injuries. The value of life in this analysis has not been estimated but the trauma associated with the loss of family and friends cannot be overstated. Reduced trauma and injury arising from improved warnings means that communities are better equipped to recover and resume essential functions such as food production, health protection and industry.
- Communities can be better prepared and reduce the loss of highly personal possession such as crafts, records or keepsakes. While some possessions may be invaluable, some, as noted in pervious assessments (Holland 2009), may include documentation essential for recovery, such as certificates of education, training or land titles.
- Avoided costs in the aviation sector of plane crashes.
- Improved weather data from radar would be expected to enable better engineering planning and design for buildings and infrastructure such as bridges, roading and or drainage. This can be expected to lead to potential significant reductions in harm to public and private constructions and substantial savings in repair costs over time.
- Other sectors that may benefit from the detection of other phenomena such as ashfall, insect or bird migrations. While these benefits may not be primary concern for the Global Environment Facility Van KIRAP project, they nevertheless contribute to overall social benefits and could even – if significant in the future – provide opportunities for future cost sharing.

None of these benefits from improved weather information were included. They are likely to be significant.

Table 38: Potential benefits from radar information not valued.

Component	Probable scale of value	Policy issue	Observation
Avoided damage to non-residential content damage (fixed assets and stock)	**High**		Significant gap
Reduced damage to agricultural machinery	Medium	Important for recovery	
Reduction in livestock loss	Medium-High	Food security issue	Significant gap
Other commercial costs avoided	**High**		Significant gap
Other infrastructure e.g., power	Medium-**High**		
Protection of life	**High**		Significant value
Reduced clean-up costs	Relatively low		
Reductions in trauma, emotional well-being	**High**	Significant in resuming normal operations	Significant value
Reduced harm from improved engineering design over time	**High**		Significant value over time

14.1.2 Other hazards that would benefit from radar information

The analysis in this document has been framed using cyclones to indicate the types of benefits that can be secured from the use of radar to inform weather and climate related decisions. In practice:

- planning and response for other hazard events such as local storms or floods could benefit from radar information. Additionally, radar information can support the tracking and avoidance of costs associated with other hazards such as volcanic ash, and
- many events that would be informed by radar data would not constitute disasters and are therefore not reported. Indeed, the intent of using radar data would be to inform and manage hydrometeorological hazards so that they do not turn into disasters. Radar information would certainly inform daily weather patterns and day-to-day behaviour of Vanuatu’s families, businesses and government operations.

As a result, the quantified benefits of radar information in this analysis are substantially underestimated.

15 Radar costs

The larger the wavelength, the greater the cost of radar systems, particularly antenna costs for comparable beam widths (World Meteorological Organization 2018). Estimates of the cost of acquiring and establishing radars for Vanuatu is based on provisional quotations and estimates from the literature of cost differentials between S band and C band radar. Recent quotes for C band radar in Vanuatu put acquisition, instalment and establishment of C band radar in the order of €1.69 million. Some vendor information indicates that S band radar – with its need for larger radome, pedestal and housing, can cost in the order of 50 per cent more depending on supplier and site works.

15.1 Maintenance and operating costs

The envisaged location of equipment and imperatives for maintenance of the project are set out in the Operating, Monitoring and Maintenance Plan for the Climate Information Services for Resilient Development in Vanuatu Project (VMGD Undated). The VMGD's Plan outlines ongoing operation and maintenance of the equipment. The Plan is based on, and aligns with, existing VMGD procedures as appropriate (VMGD Undated).

Weather radar assumed in this analysis have a life expectancy of 20 years. While systems are subject to wear and tear, weather radar are generally very reliable in practice. Nevertheless, keeping a weather radar station in full operational capacity does require regular calibration and maintenance. For example, every six months the transmitted frequency, pulse width and transmitted power should be calibrated. Maintenance on the antenna includes six monthly checks of the positioning accuracy, measuring the antenna rotation speed, checking lubricant quantity and colour (also do this every visit), and yearly replacement of the lubricant. Maintenance on the radome includes each visit checking for leaks, six monthly checks of condition (coating) and every 5 years, or more frequently if required, cleaning of the radome.

Based on the experiences of 21 countries, most outages were due to power or telecommunication failure with radar issues most commonly being with the transmitter or the antenna controllers. The signal processor is the most common upgrade. The annual costs of weather radar operations and maintenance vary between 5 – 10 per cent of radar acquisition price. This means that agencies can consequently pay as much for the running of a radar over its lifetime as it did for its purchase (Saltikoff et al. 2017).

All costs do not increase proportionally for an S band weather radar, but consumption of electricity is higher, spare parts more expensive, and maintaining the larger infrastructure will also be costlier. China Meteorological Administration has reported 25-30 per cent higher operating costs for their S band radars compared to C band radars (Saltikoff et al. 2017).

The cost of spare parts to maintain the radar system are based on previous quotes for radar and cover the first 10 years of operation. While the parts are provided as part of the quoted service, the same cost for the second decade of radar life are not included in the service and would be incurred by the VMGD.

15.2 Training

A key input when implementing weather radars will be to upgrade staff skills – training is needed as part of strategic planning included in a radar procurement or project, and is required for technical officers to operate and maintain the radar system while interpreting results. While contractors are often engaged, smaller institutes may do much themselves. When Fiji Meteorological Service installed their C band radar, the contract included a 3-year service contract with the manufacturer. This also included additional training for technicians and forecasters.

Training costs for this analysis are based on the understanding that the technicians involved have sufficient specialised theoretical training as the weather radar system involves sophisticated electronics and circuitry which requires good understanding for a technician to perform the maintenance and calibration procedure on the system. According to SPREP (Sunny Seuseu, Climate Information Services Officer, pers. comm., 11 June 2020), the Van KIRAP project has hired a full-time Infrastructure Coordinator to help weather forecasters with guidelines on representation of weather radar data in a standardized format, including identification of data type, scientific applications, operation and adopted approaches. The coordinator's role will be to coordinate and build the capacity of the Public Works Department engineers in the uptake, use and application of weather and climate information in the Public Works Department day to day decision making. The costs of this officer are already covered in project budgets and the post will be absorbed to the VMGD at the end of the project.

Economic training costs are taken from previous quotes for radar systems as well as estimations of costs of training from other supply centres (such as Australia for C band radar and the US for S band radar where S band is more commonly used). In this analysis, training is assumed to take three weeks in the year of installation, of which one week would be delivered overseas with radar experts and two weeks would be provided in-country during installation.

Cost issues are summarized in Table 39.

Table 39: Summary of cost issues.

Cost	S band	C band
Acquisition cost	Higher	Lower
Installation cost	Higher	Lower
Operating cost:		
Electricity	Higher	Lower
Infrastructure e.g., foundations, tower size	Higher	Lower
Spare parts e.g., signal processors	Higher	Lower
Maintenance e.g., cleaning of Radomes, checks for leaks	Higher	Lower
Total operating costs	5 – 10 % of radar acquisition price	

15.3 Other costs

Some costs are not included in this assessment, although they would need to be considered over time. These are:

- The cost of building a dedicated powerline extension to the radar site. In practice, the radar system can work using a generator only. However, this would be prohibitive in the long-term and costs would be minimised with a dedicated powerline.

- An access track to site for construction and maintenance. At present the state of the terrain for the proposed radar is unclear. Costs to establish an access track will depend on this.

Based on consultations with knowledgeable agencies and suppliers, assumed costs for the purpose of this analysis are presented in Table 40.

Table 40: Cost assumptions €.

Cost €	C band	S Band
Acquisition, installation and spare parts as needed for 10 years	1 590 000	1.5 times the cost of C band
Operation and maintenance	5-10% acquisition cost per annum	
Training	Training for 3 staff in years 1, 2 and 3 of radar operations	

Based on the assumptions provided, it is estimated that S band radar could cost in the order of Vt 932 million (USD$8.3 million) over 20 years, while C band radar could cost in the order of Vt 419 million (USD$3.7 million) over the same period. In other words, S band radar might be expected to be more than double the total costs of a C band radar to acquire, maintain and operate over a life of 20 years. Estimated costs for the two types of radar are outlined in Table 41.

Table 41: Summary of estimated radar costs over 20 years.

Cost	S band		C band	
	Vt	USD	Vt	USD
Acquisition and installation	299 958 000	2 674 853	199 972 000	1 783 235
Operations and maintenance	605 915 160	5 403 203	201 971 720	1 801 068
Other (parts, training)	26 128 401	232 998	16 843 997	150 205
Total estimated costs over 20-year life	932 001 561	8 311 054	418 787 717	3 734 508
Cost difference of S band radar over C band radar	223%		100%	

16 Estimated quantified payoffs

As indicated in Section 5, S band and C band radar are both utilised across the Pacific. However, there is some movement in the South Pacific towards C band radars. Providing that C band radar utilise dual polarisation radar technology, both options offer similar radar observation performance. However, C band radars come at a lower acquisition and operating cost than S band radar systems suggesting C band as a more cost-effective option.

In terms of payoffs, only a portion of the potential benefits from radar could be quantified and values are significantly underestimated:

- Most sectors are associated with estimated avoided damage and values do not include losses.
- Many sectors are not included.
- Estimated payoffs only reflect potential benefits from mitigating the effects of cyclones. Many other hazards regularly also exist in Vanuatu (flash floods, landslides, ashfall[24], local storms) and would benefit from radar information to inform decisions.
- Many sectoral estimates reflect only annual benefits from reduced costs in the case of TC Pam. They do not include the value of protecting people and assets from smaller events. As a 1 in 500-year event, there are hundreds of other sized events that would benefit from radar data, many of which would occur in the same year, including day-to day planning.

S band or C band radar are assumed to potentially secure the same level of benefits due to their similar performance capabilities. Based solely on quantified benefits, both options are estimated to be able to secure savings over 20 years of around Vt 159 million for a TC Pam-type event and Vt 105.3 million for a TC Harold-type event. It should be recognised that both these TC events occurred within a five-year period. The cumulative avoidable (largely damage) costs for both events over 20 years had radar been available are estimated as Vt 264 million (Table 42).

Due to the extra demands and costs involved, S band radar are estimated to cost over twice that of C band radar over a 20-year life span for the system. With the same magnitude of benefits, this means that the payoff of S band radar from a TC Pam-type event and a TC Harold-type event is only half that for C band radar. C band radar is estimated to generate a return per dollar invested (benefit: cost ratio or NPV) for TC Pam- and TC Harold-type events[25] of Vt 0.81 over the life of the system, while S band radar is estimated to generate a return for the same investment of Vt 0.40 per dollar over the life of the system.

Based on this approach, neither radar is estimated to generate sufficient savings to warrant their investment based on quantified values alone. Over 20 years: S band radar would result in net present losses (a negative net present value) of Vt399 million, while C band radar would result in net present losses of Vt62 million. As stressed already, however, the estimates reflect only a fraction of events which the government and community would use radar to plan for, and also reflect only selected sectors that would benefit. Accordingly, it would seem logical that the inclusion of other events

[24] P-DaLo notes 10 volcanic eruptions occurring over the 30-year period 1989-2019. However, there is no dedicated category for ashfall and it does not appear that this type of event has been commonly reported in the database.
[25] That is, should those events recur.

would actually result in a highly positive payoff for C band radar, and potentially S band radar. However, lack of data prevents assessment of the extent.

16.1 Sensitivity analysis

The calculation has been conducted using a 6 percent discount rate. If the discount rate is varied to 3 per cent, a C band radar almost pays off its investment over 20 years, based on TC Pam and TC Harold alone (Table 43).

As noted in Section 2.1.3, Vanuatu is modelled under PCRAFI to sustain average annual causalities of 41.30 people per year. Causalities includes both those injured as well as those killed and is estimated on the basis of building damage. While it is not possible to extract fatality rates from overall causalities rates in PCRAFI, it raises the question whether more lives might be protected per year with improved information on localised and severe weather events. As an indication of potential value, if the number of lives protected per year using radar is increased to two, the greater protection of earnings means that C band radar almost pays off its investment over 20 years, based on TC Pam- and TC Harold-type events alone (Table 44).

Table 42: Estimated quantified costs, benefits and payoffs for S band and C band radar Vt – 6 % discount rate.

Discount rate=6%	Total costs	TC Pam			TC Harold			TC Pam and TC Harold		
Vt$ values discounted over 20 years:		Total benefits	NPV	BCR	Total benefits	NPV	BCR	Total benefits	NPV	BCR
C band radar system	325 435 244	158 560 455	-166 874 789	0.49	105 337 787	-220 097 457	0.32	263 898 242	-61 537 002	0.81
S band radar system	663 211 412	158 560 455	-504 650 957	0.41	105 337 787	-557 873 625	0.16	263 898 242	-399 313 170	0.40

Table 43: Estimated quantified costs, benefits and payoffs for S band and C band radar Vt – 3% discount rate.

Discount rate=3%	Total costs	TC Pam			TC Harold			TC Pam and TC Harold		
Vt$ values discounted over 20 years:		Total benefits	NPV	BCR	Total benefits	NPV	BCR	Total benefits	NPV	BCR
C band radar system	362 601 735	203 698 869	-158 902 866	0.56	135 324 965	-227 276 770	0.37	339 023 833	-23 577 901	0.93
S band radar system	770 387 351	203 698 869	-566 688 483	0.35	135 324 965	-635 062 387	0.18	339 023 833	-431 363 518	0.44

Table 44: Estimated quantified costs, benefits and payoffs for S band and C band radar Vt – 6% discount rate, higher earnings saved.

Discount rate=3%	Total costs	TC Pam			TC Harold			TC Pam and TC Harold		
Vt$ values discounted over 20 years:		Total benefits	NPV	BCR	Total benefits	NPV	BCR	Total benefits	NPV	BCR
C band radar system	325 435 244	177 502 731	-147 932 513	0.55	124 280 063	-201 155 181	0.38	301 782 794	-23 652 450	0.93
S band radar system	663 211,412	177 502 731	-485 708 680	0.46	124 280 063	-538 931 349	0.19	301 782 794	-361 428 617	0.46

17 Distributional issues

Savings from radar-generated information and warnings would not be evenly distributed. For instance:

- As noted in Section 2.2.1, approximately 12 per cent of Vanuatu's population (around 270,000 ni-Vanuatu) presently live without radar coverage (Table 8). This includes residents of the national capital that hosts one third of the country's poor. The introduction of a national radar on Efate would be expected to increase coverage and contribute to risk reduction, raising those covered to at least 72 per cent of the population.
- Improvements in warning and planning capability for the fisheries and agricultural sectors will improve food security.
- In the case of agriculture:
  - 75 per cent of production is presently accounted for as subsistence production. This means that savings to production from radar will go mostly towards feeding families.
  - The majority (41 per cent) of agricultural losses from TC Pam were experienced in the province of Penama (Esler 2015) which hosts around 12 per cent of the national population. Many households also raise small livestock such as chickens, especially in rural areas. Subsistence farming is more common in rural areas and it is estimated that up to 30 per cent of the urban population has no access to land for subsistence agriculture. As a result, rural dwellers are seven times more likely than their urban counterparts to consume local foods every day (Sleet 2019). Mackenzie-Reur et al. (2018) observe that the commercial subsector is dominated by four main cash crops: 24 per cent of ni-Vanuatu households engaged in cocoa production, 50 per cent in kava, 2 per cent in coffee and 69 per cent in coconut.
  - The Global Environment Facility (2016) states that almost all households maintain a household garden for household consumption with almost all household gardens in Vanuatu being less than a hectare in size. Women are particularly dependent on agriculture with 49 per cent being involved (compared to 41 per cent for men). Based on estimated population levels for 2016 (Vanuatu National Statistics Office 2013), agricultural benefits from radar-led improved warnings for a TC-Pam event could benefit around 133,505 women (compared to around 120,000 men) contributing to equity and family food security needs.

18 Cost recovery considerations

Globally, the sector most commonly targeted for cost recovery for weather services is the aviation sector. This reflects the fact that many meteorological services were set up to serve aviation, particularly during the First World War and, while meteorological services today have many more responsibilities than servicing aviation, it remains in the majority of States a primary task (World Meteorological Organization 2007).

Reflecting this core service, World Meteorological Organization (WMO 2007) provide guidelines for cost recovery in the aviation sector. Key steps involve the identification of services provided to the aviation sector, including the airports covered, identifying the cost of each service provided and then determining an appropriate basis to allocate the costs across users (e.g., proportion of computer time spent on aviation compared to non-aviation purposes). Consistent with World Meteorological Organization guidelines, the International Civil Aviation Organization (ICAO) provides guidance for cost recovery for aeronautical meteorological services via its Manual on Air Navigation Services Economics (International Civil Aviation Organization 2013).

The Pacific Meteorological Council (2015, p. 1) have urged the uptake of cost recovery for Pacific island countries, noting that "most of the members of PMC are lacking such cost recovery mechanism(s) which results in systematic underfunding of the aeronautical meteorological services and related deficiency in service provision. In addition, lack of funding prevents the uptake of advanced technology for monitoring and forecasting of aviation weather hazards …".

In Vanuatu, provision to recoup costs from the aviation sector are provided for in Order No. 80 of the Meteorology, Geological Hazards and Climate Change Act of 2016. Under the Order, charges can be applied for three airports: Bauerfield in Port Vila, Pekoa at Luganville and White Grass Airport at Lenakel (Tanna). Under Order 80, international charges for aviation are based on set fees (Table 45), while domestic meteorological charges are varied according to the quantity of fuel purchased by aircraft (Annex 3). Additional charges apply for specific products and services such as extended forecasts or cyclone tracking (Annex 3). On these bases, revenue from airline revenue appears to total Vt 16.4 million over 2018 and Vt 17.2 million over 2019 (CAA, pers. comm., 19 June 2020) (Table 46).

Table 45: International Meteorological Fees.

Weight	Aircraft receiving basic aviation support services	Aircraft receiving enhanced aviation support services
Greater than 40 tonnes	Vt 10 000	Vt 12 000
	USD87.61*	USD105.13*
Less than 40 tonnes	Vt 4 000	Vt 6 000
	USD35.04*	USD52.57*

* https://www1.oanda.com/currency/converter/ as at June 2020.

Table 46: Aviation revenue for weather services.

	Vt	USD*
2018	16 433 316	146 543
2019	17 193 405	153 321

* https://www1.oanda.com/currency/converter/ as at June 2020.

The revenues secured reflect charges for a variety of VMGD Aviation products: Terminal Aerodrome Forecasts, Area Forecasts, Meteorological Aerodrome Reports, Special weather reports (issued when there is significant deterioration or improvement in airport weather conditions, e.g., significant changes of surface winds, visibility, cloud base height and occurrence of severe weather) and tropical cyclone subscription fees. In practice, the cost information provided for this analysis does not provide a breakdown of expenses across charge types. (All are labelled 'landing fees'.) As a result, it is not possible to determine the most valuable source of revenue presently. Nevertheless, the recording, charging and recovery of revenue for these services indicate the existence of VMGD capacity to administer charges for work and this may be used as a foundation for future revenue raising.

In addition to the landing fees, it should be noted that Vanuatu also presently recoups meteorological services via its participation in the Nadi Flight Information Region. The Nadi Flight Information Region refers to an area of upper air space covering the sovereign airspaces of Vanuatu, Kiribati, Tuvalu, New Caledonia and Fiji. Services are provided to aircraft entering this air space and cover: communications, navigation and surveillance, meteorological services for air navigation, air traffic management, aeronautical information service and search and rescue. Meteorological information is provided by national meteorological services and is recovered by them from the Nadi Oceanic Centre, the agency that manages the Flight Information Region.

Costs recovered by participating Pacific island countries are paid from Fiji as shares of the entire Nadi Flight Information Region revenue, with shares agreed via negotiations. According to the Vanuatu Daily Post/PACNEWS (2017), the present revenue shares are:

- Vanuatu 2.5 per cent.
- Kiribati 1.47 per cent.
- Tuvalu 0.59 per cent.
- New Caledonia 1.58 per cent.
- Fiji 92-93 per cent.

In 2017, it was estimated that Vanuatu secured approximately Vt 50 million as its share of upper airspace revenue fees (Vanuatu Daily Post/PACNEWS 2017).

At present it is unclear the degree to which Nadi Flight Information Region funds are returned specifically to the VMGD for its services. These may well reflect national internal planning processes.

Based on information collected at the time of writing, opportunities exist for the VMGD to increase revenue:

- By fine tuning existing charging regimes for aviation services even without radar.
- By charging for new aviation services once radar is established.
- By extending cost recovery to other sectors/ extending commercial services generally.

18.1 Fine tuning existing aviation charges

The VMGD could move from a flat rate charge for international aviation services to a resource-based rate (e.g., based on time or percentage of resources required to service international flights). A flat rate is likely to limit earnings for the VMGD: (i) because flat rates do not necessarily reflect the time spent on service provision; and or (ii) the existing rates were established in 2017 and have not been increased in spite of rising costs including inflation.

Additionally, implementation of World Meteorological Organization guidelines would certainly increase aviation-related cost recovery. Implementation of the guidelines has not yet occurred as the CAA and ISO have yet to approve the VMGD's quality management system documents and ensure that ISO certification of the aviation forecasters and an appropriate system are in place. The VMGD (pers. comm., 22 June 2020) advise that – once these provisions are secured – efforts will be made to execute World Meteorological Organization guidelines. This will include discussions with the aviation sector regarding charges and new fees.

18.2 Charging for new aviation services with radar

The introduction of radar will increase opportunities to generate revenue:

1. Presently only three of the approximately 30 airports in Vanuatu (Table 47) pay for meteorological services. These are the three International airports: Bauerfield Airport at Port Vila; Pekoa Airport at Luganville and Whitegrass Airport at Lenakel. The introduction of radar would extend this coverage to the majority of airports and enable the delivery of more weather services and associated charges.

2. The introduction of radar would be expected to significantly improve the detection capacity for weather phenomena such as local storms and lightning as well as other phenomena affecting flight safety (such as volcanic ash). This could be expected to reduce flight disruptions and enable airlines to better flight plan and minimize costs and disruptions. With increased capacity and accuracy, the VMGD could aim to increase fee rates.

3. Improved detection of flight hazards should provide the basis for future negotiations for a higher share of aviation weather service charges in the Nadi Flight Information Region. Fiji Meteorological Service increased their revenue from the airport authority and airlines due to the radar and improved forecasting of the small localised events. Presently, Vanuatu only receives 2.5 per cent of the total Nadi Flight Information Region revenue. With improved accuracy and forecast ability such as now casting[26], weather service delivery and accuracy could be tracked and provided as evidence for the VMGD to negotiate for a higher share of the Nadi Flight Information Region revenue. This may also provide an opportunity for the VMGD to negotiate internally, if needed, to ensure that the national distribution of Flight Information Region funds across government departments reflects the contribution of each department. It is noteworthy that any improvement in Vanuatu's ability to negotiate funds from the Nadi Flight Information Region would require little adjustment to existing revenue management procedures. The system to collect this revenue and distribute it across government is already place. By comparison, the establishment of new products and associated charging systems would likely involve additional staffing and administration, all of which come at a cost.

Until radar is in place, it is not possible to estimate potential increases in revenue from radar usage. However, it is worth noting that undiscounted operations costs for radar in Vanuatu for a C-band

[26] Detailed very short term forecasts made possible with radar information including the forecast of imminent small features such as individual storms.

system are presently in the order of Vt 10.0 million per year. Coverage of operations costs could be secured with a 60 per cent increase in general landing fees, a rise in FIR fees from 2.5 per cent per year to 3 per cent year[27], or a combination of both. In practice, some of the service of radar are intended for public weather services so not all radar costs might be recovered. Nevertheless the foundation for improved cost recovery does exist.

Table 47: Airports across Vanuatu.

City and/or Island	Province	Airport name
Anatom (Aneityum) / Inyeug	Tafea	Anatom Airport (Aneityum Airport)
Aniwa	Tafea	Aniwa Airport
Craig Cove, Ambrym	Malampa	Craig Cove Airport
Dillon's Bay, Erromango	Tafea	Dillon's Bay Airport
Futuna	Tafea	Futuna Airport
Gaua, Banks Islands	Torba	Gaua Airport
Ipota, Erromango	Tafea	Ipota Airport
Lamap, Malekula	Malampa	Malekula Airport (Lamap Airport)
Lamen Bay, Epi	Shefa	Lamen Bay Airport
Linua, Torres Islands	Torba	Torres Airport
Longana, Ambae	Penama	Longana Airport
Lonorore, Pentecost	Penama	Lonorore Airport
Luganville, Espiritu Santo	Sanma	Santo-Pekoa International Airport
Maewo	Penama	Maewo-Naone Airport
Mota Lava, Banks Islands	Torba	Mota Lava Airport
Norsup, Malekoula	Malampa	Norsup Airport
Olpoi, Espiritu Santo	Sanma	Olpoi Airport
Port Vila, Efate	Shefa	Bauerfield International Airport
Quoin Hill, Efate	Shefa	Quoin Hill Airport
Redcliffe, Ambae	Penama	Redcliffe Airport
Sangafa, Emae, Shepherd Islands	Shefa	Siwo Airport
Sara, Pentecost	Penama	Sara Airport
Sola, Vanua Lava, Banks Islands	Torba	Vanua Lava Airport
South West Bay	Malampa	South West Bay Airport
Tavie, Paama	Malampa	Paama Airport
Tongoa, Shepherd Islands	Shefa	Tongoa Airport
Ulei, Ambrym	Malampa	Ulei Airport
Valesdir, Epi	Shefa	Valesdir Airport
Walaha, Ambae	Penama	Walaha Airport
Whitegrass, Tanna	Tafea	Whitegrass Airport (Tanna Airport)

18.3 Extending cost recovery to other sectors/ commercial services

Other sectors that benefit from weather services could be targeted for dialogue on possible cost recovery. These include, for example, shipping which relies on up to date local weather or public works which can avoid costs with well-informed local weather information. In practice, weather information is a public good and funded to the largest degree from public funds. However, dialogue could be held to identify products that are tailored specifically for beneficiary sectors.

Options for revenue for the VMGD might include:

- Direct tailoring of weather data for specific users (e.g., farmers, tourist operators). For example, collaboration with the agricultural sector could perhaps provide scope for the development of tailored weather forecasts for businesses specific to their property. FAO (2019) observe the value of agrometeorological advisories to inform farm

[27] A rise of half a per cent per anum.

management for weather-sensitive agricultural practices such as sowing, irrigation scheduling, pest and disease control operations, fertilizer application. In any event, the development of tailored weather and or climate services through radar would require cross-department and sector engagement.

- The sharing of meteorological/ radar data with commercial agencies for tailoring and on-sale. Commercial suppliers of weather information are not unknown in the region – NaDraki (Fiji) Ltd is a private weather service based in Fiji and established as a formal business in 2010. The enterprise provides tailored weather services to a range of customers as well as providing general daily weather updates and a mobile phone App. Similarly, NIWA provides an app FarmMet (https://niwa.co.nz/news/niwa-launches-tailored-weather-forecasting-for-farmers) to support agricultural planning.

- Mobile phone and web applications, along with sales of advertising space (e.g., on the website).

Earnings theoretically could be targeted to VMGD overheads including those associated with radar, although administration of fees will themselves incur overheads.

UNDP (Mills et al. 2016) recommend that national weather services collaborate with private weather companies and embark on a phased transition to derive benefits from the national commercial weather markets. The two are linked. Importantly, a collaboration with the private sector would bring to the VMGD business and innovation skills that the VMGD may itself lack in order to market and generate demand for products, through activities such as branding, strategic media and communications, the targeting of commercially orientated product development and the development of a business plan.

Presently, the Meteorology, Geological Hazards and Climate Change Act 2016 determines that the Director of the VMGD has the right to restrict other agencies from undertaking meteorological service for public use; and to insist that – if they do obtain data – they share this with the VMGD. This would mean any public-private arrangement between the VMGD and private operators to recoup costs of weather and climate services would need to be discussed and co-developed to consider what is workable and not onerous.

In principle government agencies appear to support the concept of cost sharing/ cost recovery for weather services (Ministry of Infrastructure and Public Utilities, Ports and Harbour; pers. comm., May 2020).

19 Policy implications

19.1 Technical assessment

Based on the review and consultations conducted:

- Both S band and C band radars are used in other Pacific region countries, although the recent favouring of C band systems suggests an increasing availability of local peer support and expertise if the C band system is selected.
- Signal strength for present day C band and S band radars are similar, although S band radars may have 'an edge'.
- Due to their smaller size, C band radar are less likely to be damaged by extreme events such as storms or cyclone. This is important considering the frequency of storms and cyclones in Vanuatu.
- Theoretically S band radar has a greater range than C band radar. Although this extra range has limited use due to ground clutter at short ranges, the curvature of the Earth and the widening of the radar beam, it does provide a greater ability to pick up phenomena such as ashfall at longer distances, an issue of note for Vanuatu given its volcanic activity.

Based on the items above, but especially in view of the risk of damage and Vanuatu's exposure to extreme weather events like cyclones, C band radar would appear to offer marginal technical benefits over the use of S band radar. However, the selection of C band radar would reduce the scope to monitor and forecast events such as ashfall, compared to S band radar.

19.2 Economic payoffs

Based on the findings, due to the higher outlay and operating and maintenance costs for S band radar, C band radar offer higher expected return on investment than S band. Using a 6 per cent discount rate over a 20-year period, C band radar is estimated to generate quantified potential savings for TC Pam- and TC Harold-type events of Vt 0.81 per dollar invested, while S band radar is estimated to generate potential quantified savings of Vt 0.40 per dollar invested for the same events.

With lower discount rates, expected payoffs increase, with a C band radar coming close to paying off its investment for TC Pam- and TC Harold-type events with a 3 per cent discount rate. Similarly, if the number of lives protected per year using radar is assumed to increase from one per year to two, the greater protection of earnings means that C band radar almost pays off its investment over 20 years, for TC Pam- and TC Harold-type events. In both cases, the payoff using S band radar remains lower than for C band radar.

19.3 Overall assessment

In practice, the estimation of payoffs based on cyclones alone significantly underestimates the benefits of radar. Although lack of data precludes an assessment of radar benefits from day to day and strategic decision making and decisions concerning localised events, it is reasonable to presume that the benefits of both S band and C band radar would amply cover its costs once these benefits and intangible benefits such as wellbeing and improved engineering designs are considered. Nevertheless, the lower costs, higher durability and more common access to expertise and spare parts in the Pacific region suggest that C band radar would breakeven sooner, while retaining access to an increasing set of local (regional) users with expertise and parts.

19.4 Realisation of potential benefits – do people act on warnings?

The degree to which people may act on warnings of hazard events is unclear. In reviewing the 2009 Fiji floods, SOPAC (Holland 2009) note that:

- Many affected Nadi people did not know how to react once they received flood warnings.
- Some practices to protect possessions were unsafe (e.g., stirring flood waters in houses to prevent the mud settling on the floor).
- 19 per cent of households and 42 per cent of small to medium sized businesses did not take action to minimise flood damage even after they became aware of the oncoming flood.

Such incomplete uptake of warnings is not uncommon. Hallegatte (2012) cites Thieken et al. (2005, 2006, 2007) and Kreibich (2005) to report that only 31 per cent of affected populations around the flooded Elbe and Danube areas in 2002 implemented preventive measures.

There could be many reasons for inaction: inability to understand warnings and guidance (see Holland 2009), not being onsite in order to prepare, expectation of assistance, receiving warnings too late, and so on. In the case of warnings being received or understood too late, the timing of warnings can have a significant impact upon benefits. As an example, SOPAC (Holland 2008) observe views by senior Fiji medical staff that a three-hour warning time in 2004 could have enabled Navua medical staff to unbolt and remove the majority of critical medical machines, avoiding 25-50 per cent of the medical costs that eventuated.

The Department of Water Resources (Department of Water Resources, pers. comm., 28 May 2020) observe that the accuracy of warnings is critical for behaviour change:

> *It is vital warnings are issued with accuracy, as reputation and integrity are always at stake. It can be guaranteed that people will react very positively if warnings are issued with precision.*

Similarly, CAA (pers. comm., 19 May 2020) suggest that present weather forecasts are frequently incorrect (50 per cent hit rate), whereas radar-informed warnings would increase user confidence:

> *If there is a robust weather system in place like a weather radar system, then I will not overact and I know the weather warnings come from a state-of-the-art-technology.*

In the meanwhile, accuracy is dependent upon verification. DARD (pers. comm., May 2020) state that a challenge in presently using weather information is that it is often difficult to secure feedback from users [farmers] on the weather they experience onsite – for instance, whether it rained as predicted, whether the temperature was warmer/cooler than predicted, whether farmers had enough time to prepare after the weather warning and or how they received the information. The need for effective communications across users and the VMGD remains important for this reason.

While improved accuracy from a new radar may then enhance behaviour change following warnings, they are unlikely to obviate all costs. For example, Priest et al. (2011) review a number of studies of the impact of flood warnings on behaviour and damage reduction in Europe, observing that the degree of flood damage avoided using flood warnings can vary anywhere between 5 and 48 per cent, while Day (1970) indicates that potential damage reductions vary according to the amount of lead time that a warning provides (Table 48).

Table 48: Examples of damage reduction as a result of flood warnings in Europe.

Source	Year	Location	% reduction in potential flood damage
Smith	1981	Australia	48%
Tunstall et al.	2005	England and Wales	21% maximum Warning lead time of 8 hours = 6%
Parker et al.	2007	England and Wales	5%
Wind et al.	1999	Netherlands	35%
Day	1970	US	Varied (curve)

19.4.1 Communications

Effective communications are a prerequisite to realising potential benefits. CAA observe that Vanuatu is subject to communications interruptions – say, when internet or phone systems are downed as a result of storms. Obviously this will impede the realisation of the potential benefits of radar use as timely weather information would not be received and flight safety can then be compromised, while it can be difficult to ensure that warnings reach end users (say, farmers) in the most remote islands of Vanuatu.

Complicating the issue of physical outreach is the timing of warnings. Warnings received during the day are more likely to reach and activate communities than those issued at night when families sleep and phones are switched off. Receipt and action of warnings requires an effective dissemination network of information from radar by the VMGD to communities (e.g., through radios, television, mobile and text messages and social media).

This means that the realisation of potential benefit from radar hinge on communications infrastructure such as telecommunications and outreach. The costs of effective communications are outside the scope of the radar assessment, but these needs would logically be incorporated in the design and implementation of the institutional components of the broader Vanuatu project.

End user behaviour will be impacted by the ability of users to understand the information and respond appropriately. This is a challenge in some sectors. For example, DARD observe that sometimes it is difficult for farmers with limited education to understand the meaning – and therefore use – of probabilities in forecasts. DARD (pers. comm., May 2020) suggest that improvements are needed to help farmers respond effectively to forecasts/ warnings, suggesting, for instance, the introduction of pictorials, diagrams and colour codes to clearly illustrate points, rather than sophisticated graphs. At the same time, DARD state the need for a dedicated officer to link weather and crop performance so that it can effectively work with the VMGD to develop climate and weather updates, and structure bulletins to fit farmer needs. To this end, the Vanuatu Climate Information Services for Resilient Development (CISRD) project is contracting an Agro- Met Sector Coordinator to support linkages between meteorological information and agricultural needs and responses. The post will be absorbed into government structure when the project is complete (DARD pers. comm., May 2020).

20 Conclusions

A cost benefit analysis aims to identify and quantify the expected benefits and costs from an investment. In this analysis, a lack of data has precluded the identification and calculation of many benefits, so payoffs have been assessed through the lens of tropical cyclones. Using this approach, the *type* and potential *magnitude* of benefits from investing in radar have been identified. However, inability to capture other critical benefits – such as those from improved day to day or strategic decision making or planning related to localised events – means that all benefits are not captured in the assessment, and those benefits of radar that are estimated are minimal at best. Consequently, the estimated returns should be used as the basis for *dialogue*, not as a decision criterion.

Based on the work conducted, C band radar can be expected to break even from an economic standpoint faster than S band radar, reflecting its lower costs (Vt 325,435,244 over 20 years, compared to Vt 663,211,412[28]). This results in minimum estimated potential benefits associated with cyclones of Vt 0.81 in the dollar for C band radar compared to Vt 0.40 for S band radar. In addition , C band radar offer the prospect of wider access to localised (regional) expertise and parts for maintenance, as well as being physically more robust than S band radar. Training provided as part of radar installing and set up means that the Vanuatu Meteorology and Geoscience Department should acquire the capacity to operate and maintain the radar system, while proximity to other regional expertise and parts offers technical sustainability, if used. Based on these considerations, while C band radar lacks the technical capacity of S band radar to detect more distant (>250 kilometres) phenomena such as ashfall, C band radar would seem on balance to offer a better investment than S band radar.

As indicated, estimated benefits from investing in radar in both the case of S band radar and C band radar were minimal. Actual benefits are likely to be significantly higher:

- More benefits will accrue from strategic and day to day planning for other daily hazards and extreme hazards (e.g., flash floods and ashfall).
- More sectors will benefit e.g., commercial and industrial sectors.
- Reductions in intangible benefits such as trauma should not be overlooked.
- In all likelihood, expected changes in weather arising from climate change will increase the frequency of flash flooding and other extreme weather events (see Section 2.2). The increase in severity and frequency of these events will increase the benefits possible from radar, through improved planning and adaptation (e.g., climate informed engineering designs).

There will likely be equity benefits from the introduction of radar:

- The present radar system only covers the southern end of the country but not the poorer northern end which includes the urban centre of Luganville. As a result, a radar system that covers the northern end of the country will be expected to have important equity benefits of supporting (i) mainly rural poor; and (ii) over 86 per cent of the population up north (Section 2.2.2).

[28] Discounted at 6 per cent.

- Improved weather services can be expected to benefit the agricultural sector resulting in improved national food security, including benefitting rural communities who rely on subsistence crops, while contributing positively to women.
- Gross national income per capita is less than half that of developing countries generally (Figure 1) and economic vulnerability is high (Figure 2). Vanuatu is presently classed as an LDC with high vulnerability. Radar capability will improve forecasting for localised storms as well as improved accuracy for aviation etc., which would improve investment confidence.

In practice, once a radar for Vanuatu has been acquired, training provided and staff are utilising the system, there will be substantial operations and maintenance costs incurred by the Vanuatu Meteorology and Geoscience Department. To support cost coverage, the VMGD could consider extended cost recovery based on existing charging systems and or through charges for improved and new services possible through radar. The negotiation of an increased share of revenue from the Nadi Flight Information Region would seem to be particularly promising, not least because the administrative systems required to retrieve and distribute revenue for this are already in place and little refinement would be needed, compared to the development of new products which would require cross-department and sector engagement, planning and staffing.

20.1.1 Other issues

- Costs for the maintenance and operation of radar have been assumed for calculations in this analysis. In practice, maintenance may get neglected when departments are under financial stress and this would reduce the performance of radar and its durability. The need for ongoing maintenance is critical, including post Van KIRAP.
- Documentation of weather events for strategic planning in Vanuatu is limited, focussing understandably on large single events. The Government of Vanuatu has recently commenced post disaster needs assessments for large events which will improve long term planning. However, documentation of smaller localised events or other events that may benefit from radar (such as ashfall) impedes strategic planning and multiple small hazard events have been proven to prevent economic development (see Browne 2013 for a review). There will be value in Vanuatu working to update P-DaLo either nationally and or in discussion with SPC, along with other databases/portals that act as data hubs for disaster risk management, while targeting its own national events database.
- While improved radar capability would improve early warnings for extreme events and reduce fatality rates, the realisation of benefits relies on other items such as effective evacuation plans, uptake of warnings, communications etc.

- This assessment highlights the need for baseline data on hazard events and their costs (damage as well as loss) to provide evidence for the potential benefits of investments such as radar that enable risk management. Future assessments of investments that reduce risk or enhance capacity to plan for it will similarly rely on cost data. In all probability, cost data on historic events in Pacific island countries other than Vanuatu will also be imperfect and P-DaLo makes this apparent (see Holland 2014). This is likely to make difficult planned cost benefit analysis of projects such as *Enhancing Early Warning Systems to build greater resilience to hydro and meteorological hazards in Pacific Small Island Developing States*.

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Appendix A Terms of reference

a. Background

Climate Information Services for Resilient Development in Vanuatu

The Climate Information Services for Resilient Development in Vanuatu (known locally as Van-KIRAP – *Vanuatu Klaemet Infomesen blong Redy, Adapt mo Protekt*) aims to enhance and fill gaps in meteorological services, including new instruments to augment the observation network, technical skills training for VMGD staff, developing customized CIS tools and products for sectors and communities, and establishing effective delivery and communication mechanisms to increase awareness, dissemination and uptake.

The Project is funded by the Green Climate Fund (GCF) with SPREP as the Accredited Entity. SPREP is the regional organisation established by the Governments and Administrations of the Pacific charged with protecting and managing the environment and natural resources of the Pacific. The head office is based in Apia, Samoa with about 100 staff.

Vanuatu Meteorology and Geohazards Department and current weather radar capacity
The Vanuatu Meteorology and Geohazards Department (VMGD) provides meteorological services and supporting research in weather related activities to Vanuatu sectors and communities. VMGD is responsible for operating and maintaining its meteorological instrument network and data systems to provide fast and high-quality weather data. It requires modern, up-to-date equipment and instrumentation that is appropriate to its needs.

Through the Van KIRAP project, the Green Climate Fund (GCF) is supporting the procurement of meteorological equipment. A major equipment item under the Project will be the procurement, installation and maintenance of a weather radar system to support the provision of real-time, high resolution visualized weather data.

Weather radar is a critical component of observational networks and associated weather forecast and warning systems for national meteorological departments around the world. This technology provides real-time, high resolution visualized weather data on forecast scales of hours to days at various spatial scales (from sub-regional to national/subnational) depending on technical design and operational specifications. Such data are critical to informing reliable and accurate Climate Early Warning Systems (CLEWS).

Current VMGD weather and climate infrastructure is not considered adequate to provide national coverage of real-time, high resolution data to inform CLEWS during severe weather events, such as tropical depressions/cyclones resulting in extreme wind and rain and associated extreme sea level events (storm surge and coastal inundation). Vanuatu was struck by three tropical cyclones in 2016 (Government of Vanuatu 2017). Areas were flooded but residents were not warned due to a lack of real-time rainfall intensity sensors available to enable VMGD forecasters to forewarn the population of the amount and intensity of precipitation expected.

Existing weather radar capability for Vanuatu is limited to coverage in the southern part of the island chain from a radar installation operated in New Caledonia. However, this system is insufficient to meet existing and emerging needs for informing multi-hazards CLEWS across Vanuatu.

A weather radar on Efate (covering central Vanuatu) will enable VMGD to provide more accurate weather monitoring and forecasts that will have greater potential to reduce the loss of life and property associated with extreme weather events, including tropical cyclones. Radar will also enable the tracking of local extreme events (e.g., afternoon convection and hailstorms) which are not detectable or predictable at present. Radar will allow for better determination of rainfall rate/intensity which is important for determining the potential for flash flooding and landslides.

Improved tropical cyclone tracking is also possible in central Vanuatu with radar. This is important as more than half of Vanuatu's population live in the central islands. Better forecasts lead to greater public confidence in VMGD services. Conversely, radar will also help reduce the number of incorrect weather forecasts.

In a future warmer climate, tropical cyclones are predicted to become more intense in terms of wind speed and rain intensity. A radar on Efate has the potential to reduce the number of lives lost by providing more detailed and accurate forecasts of extreme rainfall and flash flooding associated with tropical cyclones and storms.

The procurement and installation of a radar will also enable VMGD to develop mesoscale forecasting which is currently not possible with the manual observation network. Additionally, the radar can be used to detect the extent of volcanic ash clouds and direction of movement of the ash cloud.

b. Intended use and functions of equipment

This Terms of Reference covers the following elements on the intended use and functions of the required equipment (weather radar system) within Vanuatu. The intended use of the weather radar system within Vanuatu will provide for:

a. Improved and accurate weather monitoring and forecasts.
b. Tracking of local extreme events (e.g., afternoon convection and hailstorms) which are not detectable or predictable at present.
c. Improved determination of rainfall rate / intensity. This is important for determining the potential for extreme rainfall and flash flooding enabling hazard warnings to be issued more accurately and in more timely fashion with consequent of reduced loss of life and property from extreme events.
d. Development of mesoscale forecasting which is currently not possible with manual observation networks.
e. Detection of the extent of volcanic ash clouds and direction of movement of the ash cloud.
f. Provision of additional information to enable VMGD to provide real-time data to a range of sectors including the marine (ship/vessel marine forecasts) and aviation sectors.

c. Objectives

This engagement seeks to develop a comprehensive cost-benefit analysis on equipment to be procured by the project including the rationale for equipment and building of a business case for the installation and ‘life-of-equipment’ operations and maintenance. The engagement is also seeking to gain insights into potential revenue streams to support the ongoing maintenance and upkeep of the equipment and systems.

d. Scope

SPREP requires an in-depth cost-benefit analysis report focusing upon:

a. A comparison of Weather Radar systems currently available on the market (i.e., S-band, C-band and X-band etc.,) investigating capability as per the criteria outlined below. The system must be compatible with comparable systems operational in the Pacific region.

   The proposed weather radar must meet minimum standards as per the World Meteorological Organization (WMO) standards (WMO 2008) or Australian Bureau of Meteorology (BOM) standards (Gillespie 2017). Weather radar standards and SOPs for VGMD use will need to be developed during the Van-KIRAP project. Ideally the same type of radar is in use elsewhere in the Pacific region. The contractor(s) will ideally have some experience in the Pacific region and meet minimum quality assurance standards and certification. At a minimum ISO9001:2008 certification should be attained.

   The most appropriate fundamental radar technology should be selected to obtain best value in terms of data quality, operational reliability and maintainability. This must be considered in terms of appropriate siting for optimum detection coverage, availability of suitable supporting resources and infrastructure, and reliability of the technology in accordance with required performance criteria for the projected lifetime of the system.

   Criteria for the weather radar which are critical to radar technology and radar system selection includes:

   1. Range resolution
   2. Ability to penetrate multiple bands of precipitation
   3. Ability to discriminate between different types of precipitation
   4. Ability to reject spurious return signals and artefacts
   5. Operational reliability and availability
   6. System maintainability
   7. Flexibility to tailor system parameters via software (e.g., scans, filters and data products)
   8. Display and visualization capability

b. A review of operational Weather Radar systems in the region e.g., Fiji, New Caledonia, Australia and New Zealand – to assess comparable systems and explore existing capacity of these systems to support Vanuatu's needs.

c. An assessment of the technical, financial capacity of the Vanuatu Meteorology and Geohazard Department (VMGD) in the sustainability aspect of the Weather Radar system.

d. A detailed report on proposed revenue streams that the Weather Radar system can contribute to. The revenue streams will be to support the maintenance and upkeep of the equipment and focus on a number of options available.

e. Deliverables

The Consultant will be responsible for delivering the following outputs:

(i) A final report including:

   a. Addressing the business case for weather radar systems including the social and economic benefits of weather radars.

b. Provide a detailed comparison between weather radars and their capability of meeting the requirements of Vanuatu.
c. A detailed comparison between weather radars on procurement and installation costs.
d. A detailed comparison between weather radars on life-of-equipment maintenance, upkeep and operational costs.
e. Overall requirements, recommendations to assist in defining subsequent procurements and costs.

(ii) An assessment of the technical, financial capacity of the Vanuatu Meteorology and Geohazard Department (VMGD) in the sustainability aspect of the Weather Radar.

(iii) A report on potential revenue streams from the procurement and installation of the weather radar system.

f. Selection Criteria

The consultant must demonstrate that they have the level of experience and ability to provide high quality services of a similar type to those sought under this Request for Tenders by providing information on qualifications, professional experience and references for professional ability. Satisfactory references demonstrating the successful delivery of two (2) contracts where work of a similar type to that required under this tender must be provided.

The selection criteria used to determine the successful consultant are outlined below. The criteria are not in any order or to be given equal weighting.

Criteria are as follows:

i. Experience

- Curriculum vitae of consultant outlining previous experience
- Proven track record with a minimum of five years' experience in undertaking cost-benefit analyses in similar environments
- Qualifications in economics, finance, science, geoscience or social sciences
- Demonstrated background in the field of meteorology
- Strong knowledge of the Pacific observational networks

ii. Proposed Project Methodology

- Detailing activities to be conducted over the term of the engagement, including detail on how each activity will be undertaken.

g. Other Information

1. It is expected the consultant will need to spend time in the participating country liaising directly with existing project staff to undertake the required information gathering, and analysis of requirements for this Terms of Reference.

2. All in-country arrangements and support from country counterparts will necessarily be initially arranged through SPREP and no direct contact should be made until official introductions are made. The successful consultant will be provided with any appropriate documents identified and saved by SPREP as part of the preparation for the activity.

Appendix B Fee basis for domestic meteorological services and products

Table B1: Domestic Meteorological Fees.

Types of fuel	fees per litre
Aviation turbine fuel	Vt0.4
Aviation gasoline	Vt0.7

Table B2: Fees for products and services.

<table>
<tr><th>Product/ service</th><th>Fee Vt</th><th>Format</th><th>Comment</th></tr>
<tr><td>Insurance report</td><td>20 000</td><td rowspan="5">PDF (email), A4 (printout)</td><td>When requested</td></tr>
<tr><td>Extended forecast (3-7 days) (land)</td><td rowspan="2">12 000 (6-month subscription)</td><td rowspan="2">7-day forecast (free on VMGD website, radio or call office directly)</td></tr>
<tr><td>Extended forecast (3-7 days) (marine)</td></tr>
<tr><td>TC bulletin and forecast track maps (48 hours)</td><td>15 000 (per cyclone season subscription)
100 (printout per warning)</td><td rowspan="3">Free on VMGD website, radio or call office directly)</td></tr>
<tr><td>Severe weather</td><td>12 000 (6-month subscription)
100 printout per warning</td></tr>
<tr><td>Vanuatu cyclone tracking map</td><td>100 printout per copy</td><td>A4 (printout)</td></tr>
<tr><td>Tide prediction</td><td>300 per page</td><td>A4 (printout)</td><td>Free on VMGD website, radio , daily Post and Independent Newspaper</td></tr>
<tr><td>Climate Change Report</td><td>20 000 per copy</td><td>Book</td><td>From VMGD office</td></tr>
<tr><td>Weather data for projects</td><td>10 0000</td><td rowspan="2">Excel format, email</td><td rowspan="4">Included in project proposals</td></tr>
<tr><td>Earthquake data for projects</td><td>20 000</td></tr>
<tr><td>Volcano/seismic data for research</td><td>[not specified]</td><td>Digital</td></tr>
<tr><td>Weather data for research</td><td>20 000</td><td>Excel</td></tr>
<tr><td>Earthquake information</td><td>24 000 (12-month subscription)
100 per copy</td><td rowspan="2">PDF (email), A4 (printout)</td><td rowspan="2">Free on VMGD website, radio or call office directly)</td></tr>
<tr><td>Earthquake information</td><td>12 000 (6-month subscription)
100 per copy</td></tr>
<tr><td>Volcano hazard and risk maps</td><td rowspan="2">1 000 per copy</td><td rowspan="2">PDF (email), A4 b+w printout, A4 colour printout, A3 colour printout</td><td rowspan="3"></td></tr>
<tr><td>Earthquake hazard and risk maps</td></tr>
<tr><td>River flood hazard and risk maps</td><td></td><td>PDF (email), A4 b+w printout, A4 colour printout</td></tr>
</table>

<table>
<tr><th>Product/ service</th><th>Fee Vt</th><th>Format</th><th>Comment</th></tr>
<tr><td>Landslide hazard and risk maps</td><td rowspan="4">1 000 (printout per copy)</td><td rowspan="5">PDF (email), A4 b+w printout, A4 colour printout, A3 colour printout</td><td rowspan="5">Free on website</td></tr>
<tr><td>Wind hazard and risk maps</td></tr>
<tr><td>Coastal inundation hazard and risk maps</td></tr>
<tr><td>Tsunami hazard and risk maps</td></tr>
<tr><td>Combined maximum risk apps for planners</td><td>1 500 printout per copy</td></tr>
</table>