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Hydroclimatic Analysis of Climate Change Risks to Global Corporate Assets in Support of Deep-Dive Valuation

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Abstract: Climate change poses both risks and opportunities for business, now and in the future. However, investors, lenders, and insurers currently lack quantitative tools to view which companies will endure or flourish, and which companies are resilient or not. Measuring, managing, and reporting environmental impacts is not only important for the planet and the communities in which we work, but also essential for the future growth of our businesses. Among the key climate-related risks to society and business in particular are hydroclimatic risks (i.e., flood and drought). Projecting change in these risks are essential for the design, operation and management of public and private infrastructures. This is particularly true for large multi-national enterprises where their infrastructure and supply chains are located and connected across a wide-range of hydro-climatic zones. For the most part, public infrastructure in the industrial nations and private multinational production facilities have been designed to address current hydroclimatic risks. Regardless of these measures, we are faced with an unavoidable changing environment, which will alter hydro-climatic extremes and risks.

In light of these considerations, the primary objectives of this endeavor are to assess the change in hydro-climatic risks to the global landscape of a corporation's infrastructure by providing: (1) weather and climate-induced impacts across the global hydrologic and water resources system; (2) conditions leading to weather, climate, and hydrologic extremes and their resultant hazards; and (3) risk-based projections of these changes for a selection of key facilities and supply-chain junctures.

The analysis presented is performed on the actual global facilities of an anonymous global corporation, which hereafter will be referred to as GloCorp. A risk-based Indicator framework is developed. The framework utilizes an ensemble of hybrid frequency distribution (HFD) climate scenarios from the MIT Earth Systems Model with an enhanced version of the World Bank's Climate Risk Hydro Indictors. The results suggest that by 2030, 61% of all facilities face a Medium or High Climate Risk. However, as climate change intensifies over the coming century, the impact on GloCorp's facilities increases. By 2050, it is projected that 90% of all facilities face a Medium or High Climate Risk.

1. Background

Today, risks across public, private and corporate infrastructure are increasing – primarily caused by changes in our natural, managed, and built environments and resource systems. More than ever, strategic planning requires comprehensive assessments of exposure and vulnerability as well as best-response practices to interwoven challenges and potential threats. This capability should enable a better flow of information between science and industry, bridging not only the risk assessment and decision-making processes, but also enabling the disclosure of climate risk in investment portfolios, in accordance with the recommendations of the Task Force on Climate-related Financial Disclosures (TCFD).

Hydro-climatic processes and hazards are the result of strong connections between the climate and surface-hydrologic systems. The most salient responses and hazards are primarily caused by precipitation, temperature and other extreme atmospheric conditions – and can extend across large regions of the global landscape. Climate and weather extremes result from a number of geophysical, dynamical, and biological processes that include strong, unstable oscillations in the atmosphere; complex cloud, radiative and thermodynamic processes; tropical/extra-tropical interactions; ocean-air interactions; and the responses of terrestrial eco-hydrological systems to atmospheric influences (e.g. National Academies, 2016). Much of the attention in hydroclimatic risk focuses on extremes such as flood and droughts whose impacts can be amplified by concurrent and/or compounding temperature, humidity, and/or wind conditions. Understanding the globe's current hydro-climate, water resources, and water-related hazards as well as projecting the risks of change in all these hazard effects are essential for the design, operation and management of public and private infrastructures. This is particularly true for large multi-national enterprises where their infrastructure is located across a wide-range of hydro-climatic zones. For the most part, public infrastructure in the industrial nations and private multinational production facilities have been designed to address current hydroclimatic risks. However, the globe is facing a changing climate due to greenhouse gas emissions. Moreover, a considerable degree of irresolution remains in the degree to which the nations of the world will cooperate to drastically reduce these emissions. Regardless of these measures, we are faced with an unavoidable changing environment, which will alter hydro-climatic extremes and risks.

1.1 Assessing Hydroclimatic Risks at a Global Scale

There exist a number of global assessments on current hydroclimate risk. For example, The International Water Management Institute (IWMI) has provided a global assessment of water scarcity (**Figure 1**) based on mean annual water availability (IWMI 2006). The metric provides important geographic insights between water stress as a physical or economic risk, and indicates that for many developing regions of the world, inadequate water supplies could limit economic growth. Yet, clearly these hazards will shift and alter as water supplies change, and the uncertainty behind the drivers of change necessitate a risk-based approach. In other assessments of the contemporary landscape, global flood risk has been diagnosed by the World Bank and Columbia University (**Figure 2**), and a global drought risk

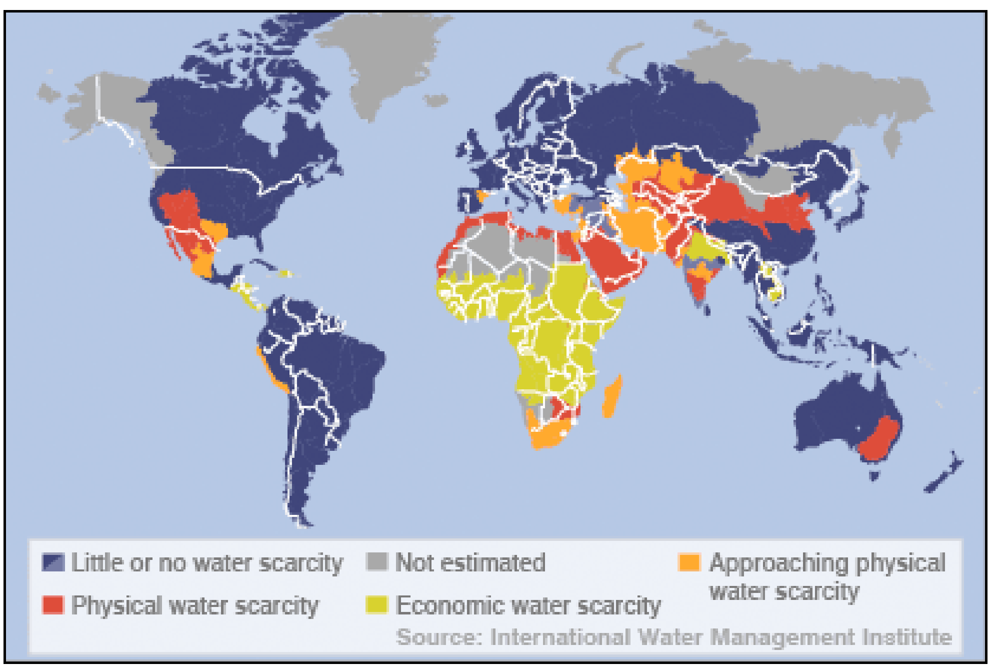

Figure 1: A Global Water Scarcity Index provided by the International Water Management Institute (IWMI,2006).

analysis was performed by the Joint Research Centre of European Commission (EC) (**Figure 3**). Collectively, these assessments provide a visual and qualitative perspective of the coincident and compounding extent of these different stressors and threats. To date however, an efficient, integrated, quantitative, and prognostic framework that allows stakeholders to prioritize threats and subsequent deep-dive investments for research and action is needed.

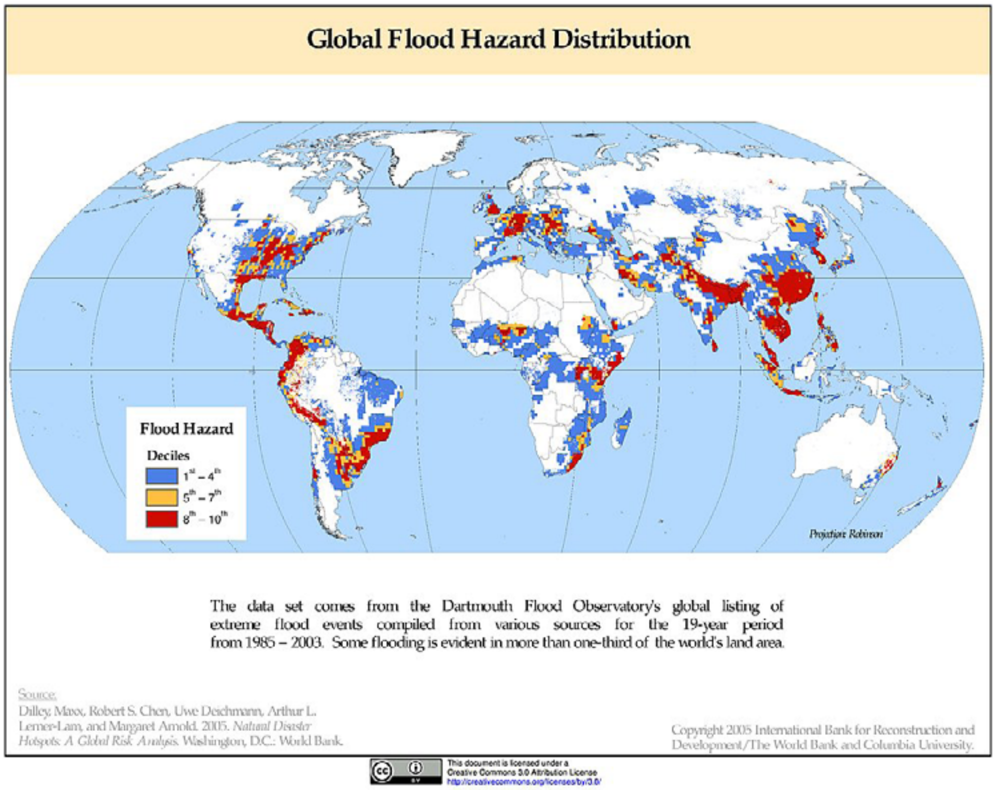

Figure 2: A Global Flood Risk map provided by a study from the World Bank and Columbia University. (Dilley, *et al* 2005)

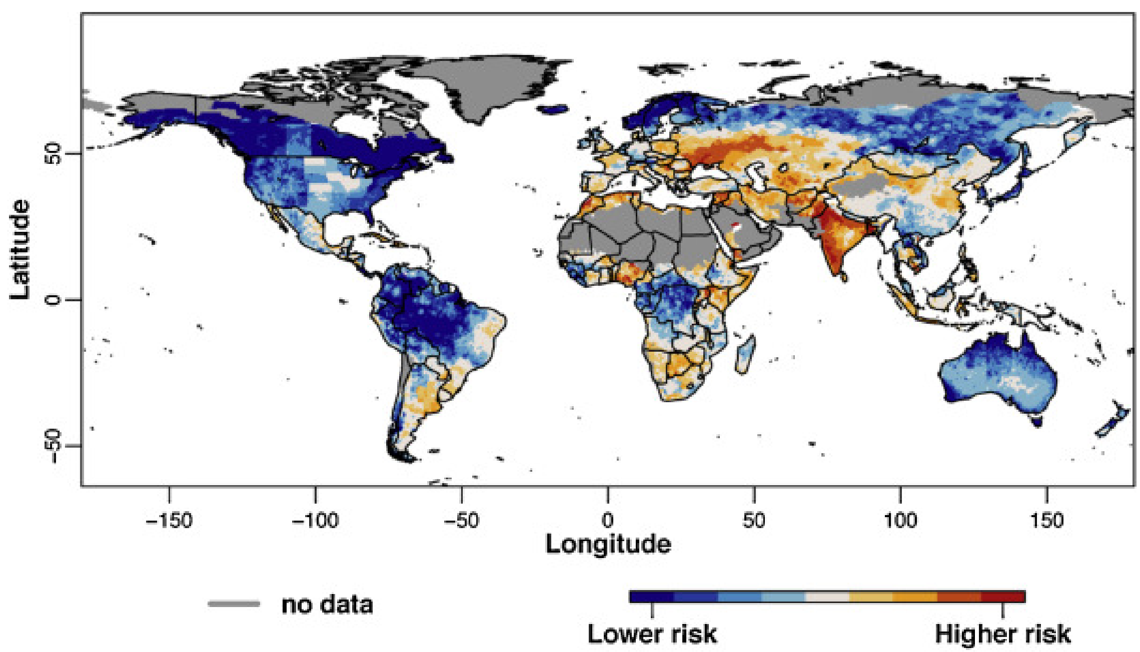

Figure 3: A Global Drought Risk assessment conducted by the Joint Research Centre of European Commission (Meza, 2019)

1.2 Hydroclimatic risks in a world with a changing climate

For the most part public infrastructure in the industrial nations and private multinational production facilities have been designed to address current hydroclimatic risks. However, the globe is facing a changing environment due to human-forced climate drivers, and these in turn will also lead to changes in extremes and hydroclimatic risks. The USEPA recently undertook a National Hydroclimatic Change and Infrastructure Adaptation Assessment. They state:

> *"As described in IPCC (2007), hydroclimatic changes in the next 30-50 years in long-term master planning will become recognizable during the 21st century and can impact the service of nation's water resources and infrastructure.... The contiguous U.S. in the past century appears to have witnessed a marked difference in hydrologic changes to the non-stationary climate system. Each hydroclimatic province behaved differently. ... This evaluation considers three major factors in conceptual levels: the change and the rate of hydoclimatic changes, the uncertainties in the hydroclimatic change predictions, and the planning time horizon. When the rate of climate change is excessive within the time period of concern, the existing practices in hydrologic design and water resource management may be inadequate. This is particularly true for large uncertainties in projection-based design parameters.... Climate change vulnerability assessment may be a necessary pre-requisite."* (Yang *et al*, 2009)

The issues addressed and insights gained are even more apropos for global scale multinational enterprises whose facilities and supply chains are currently susceptible to a wide range of hydroclimatic risks and will undoubtedly face increased and more complex risks under a changing global environment.

2. Research Objectives

In light of these considerations, the primary objectives of this endeavor are to assess the change in hydro-climatic risks to the global landscape of a corporation's infrastructure by providing: (1) weather and climate induced impacts across the global hydrologic and water resources system, (2) conditions leading to weather, climate, and hydrologic extremes and their resultant hazards, and (3) risk-based projections of these changes for a selection of key facilities and supply-chain junctures.

The analysis presented was performed on the actual global facilities of an anonymous global corporation, which hereafter will be referred to as GloCorp. **Figure 4** provides an illustrative map of likely sites of this hypothetical global corporation drawn from data from a wide range of data of global corporations across a range of industrial sectors. This does not represent actual location on any corporation, but rather to provide the reader with a sense of the spatial extent of many of today's global corporations. The case study is to demonstrate the capability of this methodology for screening climate risks at global scale to allow corporations

Figure 4: Illustrative facilty locations of a hypothetical global corporation (this does not represent actual location of any corporation)..

to undertake more detailed studies or actions at regional sand/or local site scales.

The primary objective of this research is to identify the Change in Hydroclimatic Risks to GloCorp's Infrastructure from Climate Change by identifying (1) climatologically induced relations across the global hydrologic and water resources system, (2) conditions leading to climatological extremes and resultant hydrologic hazards, and (3) identifying the uncertainties around the projection of these changes across the GloCorps global facilities (Figure 4). For presentation of aggregated results, the GloCorp facilities are sorted into western or eastern hemisphere and by tropical or extra tropical (See Figure 4). This produces four geographic regions: 1) Eastern-Extra Tropics, 2) Eastern-Tropics, 3) Western- Extra Tropics, and 4) Western-Tropics,

3. Methodological Framework

3.1 Indicators of risk

This presented analysis' aim is to provide a robust yet tractable evaluation of the changes in hydroclimatic risks due to climate change at the local scale for GloCorp facilities. In doing so, an understanding of the relative change in variable values, not absolute magnitudes of variable values is determined. The results therefore provide an understanding of the range of potential consequences of climate change on risk at the facility scale. These results are suitable as inputs to further screening-level analyses of the impact of climate change on the location, new design, renovations and management of GloCorp research and production facility investments.

The methodology used here is an extension of the work developed by Strzepek *et al.* (2011) and Strzepek *et al.* (2013) for the World Bank. The methodology assessed the impact of potential climate change to hydroclimatic risk on their current and potential World Bank water resources infrastructure portfolio. The World Bank analysis incorporates a rigorous assessment of climate change outcomes for river basins of the world, including monthly meteorological variables, and selected hydrological indicators as determined from 22 general circulation models (GCMs) projection of future climate. The modeling process used to achieve this is presented in **Figure 5.**

We have expanded upon the approach of the World Bank study by implementing three extensions:

1. A more extensive assessment of the uncertainties surrounding the GCMs outputs: We combine the results from the MIT Integrated Global Systems Model (IGSM) with emerging response patterns from the GCM outputs to create a hybrid meta-ensemble. The technique provides "Hybrid Frequency Distribution" (HFD) scenarios that effectively expand the model sample-size from 22 to 6,800 (Schlosser, *et al,* 2014) .
2. Addition of two indicators: These additional metrics reflect the degree and range of uncertainty in the projections of the climate change impacts as well as the indicators of hydroclimatic risk, and
3. A new indicator for Sea Level Rise Risk

As shown in Figure 5, the hybrid approach of the IGSM framework lies at the core of the climate-risk analysis

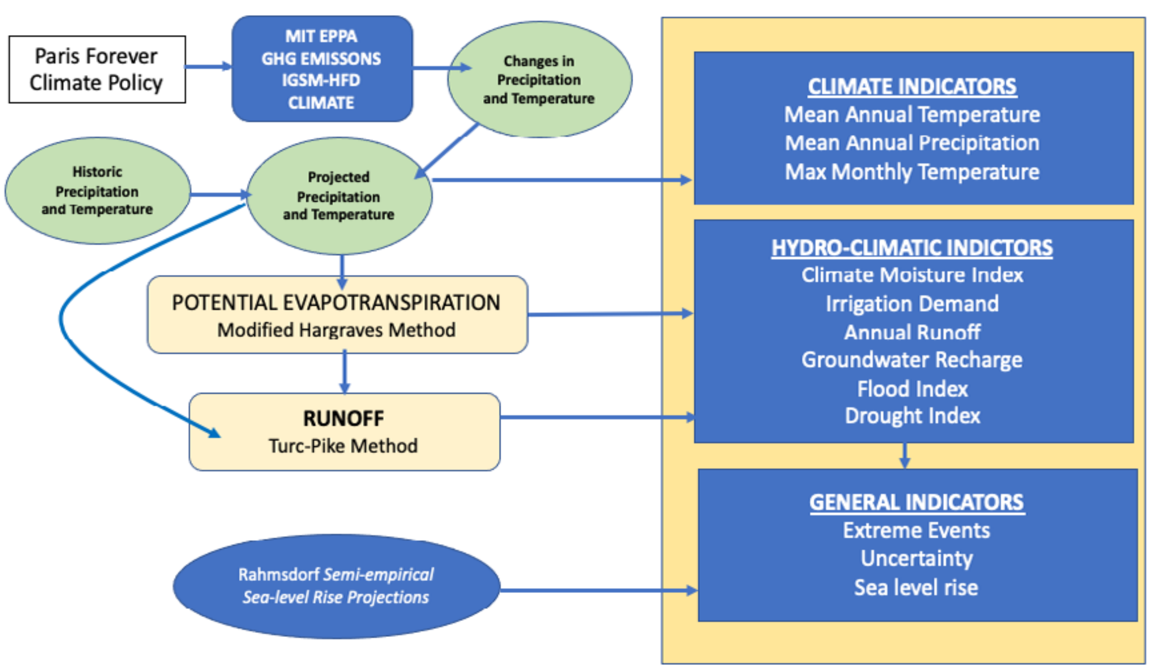

Figure 5. Information flow of Climatic Variables and Modeled Hydro-climatic Variables for Indicator Development.

process. Projected changes in monthly temperature and precipitation for the 2030s (2025–2035) and the 2050s (2045–2055) were collected from the large ensemble of future outcomes (6,800 plausible futures constructed in this study). Changes in these parameters were calculated from the historical baseline of 1980 to 1999. These HFD scenarios, which consider not only a "business as usual" trace-gas emissions scenarios but also various emissions reduction pathways, can provide uncertainty for a variety of input variables (discussed in next section), and reflect the large variability in possible precipitation and temperature outcomes, as well as the likely variation in spatial distribution of these outcomes. Monthly HFD outputs were used in this study to capture seasonal variability in meteorological conditions over the year. The 2030s and 2050s were selected as the appropriate timeframe at which to evaluate the impacts of climate change on various hydrologic variables for two reasons: this is the relevant time-scale for current infrastructure planning, and uncertainties in projections increase dramatically beyond 2050. All the indictors are calculated over a 2 degree by 2-degree common, global grid and each of the 60 GloCorp facilities is mapped to the grid in which they fall. Once projected changes in monthly temperature and precipitation for the 2030s and 2050s were gathered from all HFD scenarios, these projections were then combined with historical data for the baseline period—1980 to 1999—to produce absolute temperature and precipitation projections for each basin.

3.2 Hydroclimatic risk

Strzepek *et al* (2013) developed a set of hydrologic indicators to assess potential risk of climate change on water resources for those involved with World Bank water resource development projects. Starting with the World Bank framework and drawing insights from a growing discussion on hydro-climatic risk indicators (Visser, *et al.*, (2020), Arnell, N.W., (2020) de Almeida, *et al* 2016, McIntosh and Becker ,2016, Gassert, *et al.*, 2014, . Gassert, *et al,* 2013 and Nashwan, *et al,* 2018), indicators were chosen for this analysis with the intent of providing information relavant to corporate global asset climate risk management.

The indicators chosen include the following: two GCM outputs, temperature and precipitation; two calculated meteorological variables, PET and CMI; and six hydrologic variables, MAR, basin yield, annual high flow (q10), annual low flow (q90), groundwater (baseflow), and reference crop water deficit. Below we provide further details into how the meteorological and hydrologic variables are calculated.

Two calculated hydro-meteorological variables are used:

1. Potential evapotranspiration (PET) represents the amount of water lost through evaporation and transpiration (that is, water consumed by vegetation) over a specified time period under the condition that sufficient water is available at all times. PET depends upon several variables, including temperature, humidity, solar radiation, and wind velocity. This work employs the Modified Hargreaves model (Allen *et al.*, 1998, Droogers and Allen, 2002) for PET that is a well accepted reduced form equation that is based on observed temperature and precipitation and (latitude-based) incoming solar radiation.
2. Climate moisture index (CMI, Willmott and Feddema, 1992) computed using the ratio of annual precipitation (P) to annual potential evapotranspiration, (PET). al., 2004. The CMI illustrates the relationship between plant water demand and available precipitation. The CMI indicator ranges from -1 to +1, with wet climates showing positive CMI, and dry climates negative CMI.

   Climate Moisture Index (CMI) = (P / PET) - 1 when P < PET OR
   Climate Moisture Index (CMI) = 1- (PET / P) when P ³ PET

While temperature, precipitation, PET, and CMI are useful indicators of climatic and hydro-meteorological conditions, six additional indicators provide important aspects of (land) surface and subsurface hydrology. These are based on runoff projections, inputs of PET, absolute temperature, and absolute precipitation projections and employ the Turk-Pike hydrologic runoff model (Yates, 1995). These processes and calculations are described in Appendix 2

Using the output from each of the HFD ensemble members, a 50-year monthly runoff time series is generated from the Turk-Pike hydrologic runoff model, and the following six hydrological indicators are generated.

- **MAR:** the average annual runoff across years in a given period, for example, the 2030s.
- **Basin yield:** the maximum sustainable reservoir releases within a basin.
- **Annual high flow (q10):** the annual runoff that is exceeded by 10 percent of years in a given period, also referred to as the 10 percent exceedance flow. In a 10-year period, the q10 flow would be the second highest flow of the 10 available, which is exceeded only by the highest flow in that decade. Change in q10 is used as an indicator of flood risk.
- **Annual low flow (q90):** the converse of annual high flow, this is the 90 percent exceedance flow, or the annual runoff that is exceeded by 90 percent of years in a designated period. For a 10-year period, this would correspond to the second lowest recorded flow. Change in annual low flow is used as an indicator of drought risk.
- **Groundwater (baseflow):** the sustained flow in a river basin resulting from groundwater runoff. This indicator is used as a proxy for groundwater availability.

- **Reference crop water deficit:** the crop water demand that exceeds available precipitation. Because it was not possible for this study to measure biophysical crop water demand, PET was used to represent the water demands of a typical perennial grassland.

The three additional indicators added for this analysis are:

- **Sea-level-Rise**: We have used the dynamic global sea-level rise projections from Rahmsdorf (2007, 2012).
- **Uncertainty Indicators**: There are two indicators that measure of the range of the uncertainty across the HFD ensemble-member estimates of CMI for each grid based on the HFD projections of monthly temperature and precipitation changes as illustrated in **Figure 6**. One is the ratio of the median to the interquartile range (boxes in Figure 6) and second is the range of maximum outliers (whiskers in Figure 6)
- **Extremes Indicators**: There are two indicators that measure of the number and sign of outliers or extreme values across the HFD ensemble-member estimates of CMI for each grid as illustrated in Figure 6. One is the total number of "outliers" (above or below 1.5 times interquartile range from the mean) and the second, is relative preponderance of these outliers toward one sign of CMI change (i.e. increasing or decreasing CMI change).

3.3 From Indicators to Risk Index

Now that the hydroclimatic indicators are calculated, the next step in the framework is to develop corresponding climate risk indices for each of the indicators. Each indicator is mapped to a 3 level Climate Risk Index. The index is designed to classify the projected changes in the hydroclimatic indicators into three classes of potential risk that each particular variable may pose to an industrial facility: low, medium, or high risk. The risk classes are designed to communicate the following threats:

Low Risk: Climate change appears to not significantly increase and may even decrease the overall hydroclimate risks at this location:

Medium Risk: Climate change appears by either mean impacts or potential extremes across the HFD scenarios to moderately increase the hydroclimatic risks at this location. Further local detailed climate change impact and adaptation analyses should be undertaken if this is a highly critical facility in the GloCorp business chain or this location is currently highly vulnerable to current hydroclimatic risks.

High Risk: Climate change appears by either mean impacts or potential extremes across the HFD scenarios to significantly increase the hydroclimatic risks at this location. Further local detailed climate change impact and adaptation analyses are highly recommended.

These classifications are qualitative and the mapping of quantitative indicators to these indexed levels may appear to be subjective. However, the classification approach used in this work is based on concepts by Saarikoski *et al* (2016), Jalal and Rogers (2002) and Sands and Podmore (2000) to enhance the original work on HydroIndicators by the World Bank (Strzepek, *et al* 2013). This literature has been

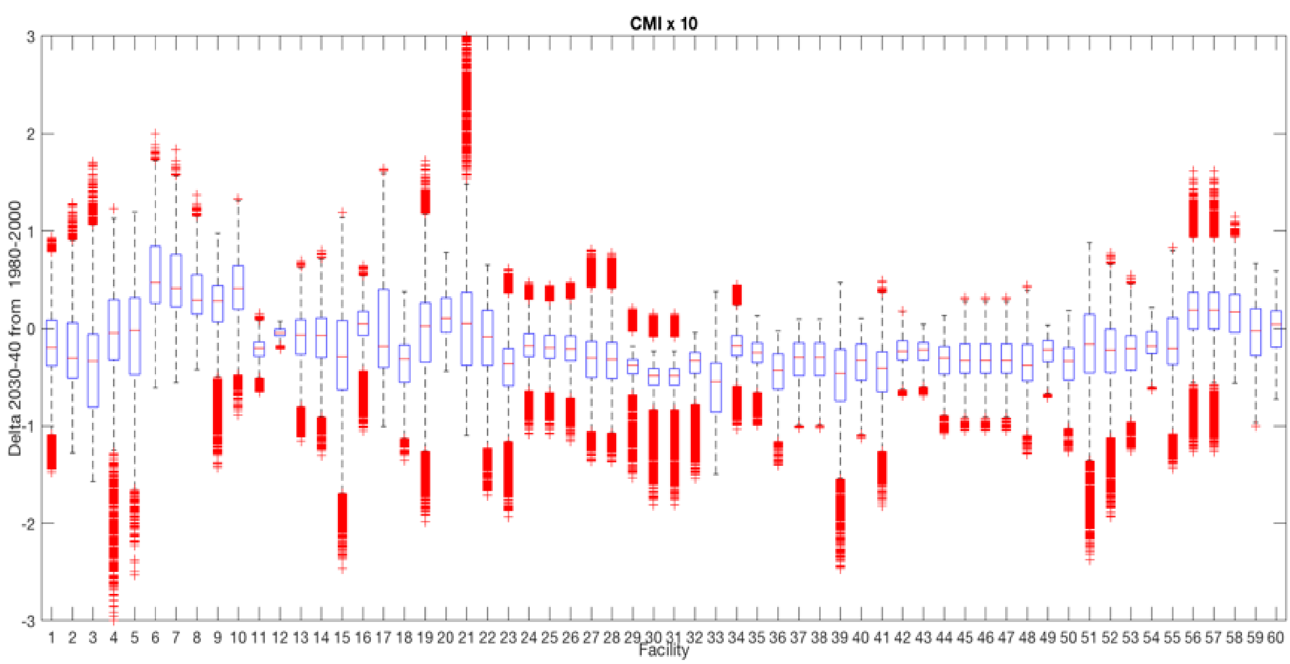

Figure 6. The Uncertainty from the HFD scenario for CMI for all 60 GloCorp Facilities

combined with recent experiences by the authors working on developing criteria for design of climate resilient infrastructure for a range of public and private stakeholders.

The classification process employed was to establish a threshold for each indicator if the value of the indicator was below that threshold it would be classified as a low risk. if the value was above this threshold and lower than the high risk threshold it would be classified as a medium risk. If the value was above the high risk threshold any would be classified as a high risk.

Table 1 lists the threshold values that were applied to the 13 indicators and **Table 2** is an illustration of the process for a specific Global Corp Facility.

Finally, a composite or total Climate Risk Index is calculated for each facility to provide a comprehensive metric of climate change risk to the facility. The total climate risk index is customized to reflect the aspects of climate impacts class that may threaten specific facilities. The climate impacts considered for each facility are 1) coastal location, 2) local agricultural products in the supply chain, and 3) non-agricultural general climate threats. Table 1 provides the allocation of the Climate Risk Indices to each of the climate impacts classes.

The Total Climate Risk Index is calculated by summing the relevant climate risk indices for each location (0 for low risk, 1 for medium risk, and 2 for High Risk) and calculating the ratio of the sum to the total sum if all relevant

Table 1. Data for Risk Index Classification

Indicator	Facility Type	Direction of Change		Low Risk Threshold	High Risk Threshold
Coast	Coastal	increase	absolute	Mid	High
Ann Temp	NonAg	increase	Delta	0.5	1
CMIx10	NonAg	decrease	Delta	-1	-2.5
Max T	NonAg	increase	Threshold	28	30
Ann_Precip	Ag	decrease	%	-5	-15
Ann_PET	Ag	increase	%	5	15
Irrig_Def	Ag	increase	%	5	15
Ann_Runoff	NonAg	decrease	%	-5	-15
Ground_Water	NonAg	decrease	%	-5	-15
Flood	NonAg	increase	%	5	15
Drought	NonAg	decrease	%	5	15
Uncertain	NonAg	increase	absolute	2	3
Extremes	NonAg	increase	%	0.5	-3

Table 2. Example of Risk Index Classification

Manufacturing Facility	Indicator	Low Risk Threshold	High Risk Threshold	Risk Class
Coastal	Low	Mid	High	0
TempC	1.5	0.5	1	2
CMIx10	-0.6	-0.1	-0.25	2
MaxT	25.4	28	30	0
Ann_Precip	-2.8	-5	-15	0
Ann_PET	5.0	5	15	0
Irrig_Def	42.7	5	15	2
Ann_Runoff	-5.1	-5	-15	1
Ground_Water	-19.9	-5	-15	2
Flood	-0.3	5	15	0
Drought	-5.8	5	15	0
IQR_cov	-0.4	2	3	1
WSK_cov	-1.4	-2	-3	2

Table 3. Total Climate Risk Threshold Levels

Facility Type and Relevant Climate Indicators	Indicators	Low Risk Sum Threshold	High Risk Sum Threshold
Coastal with Ag	13	9	13
Coastal without Ag	10	7	10
Non-Coastal with Ag	12	8	12
Non-Coastal without Ag	9	6	9

indices were at high risk. The thresholds for mapping of this ratio to Risk Index were 0.33 for Low Risk and 0.5 for High Risk. **Table 3** lists the summation threshold levels for the range of climate impacts classes that the facilities fall. **Table 4** presents the calculation of the Total Climate Risk for the Facility presented in Table 2.

4. Results

4.1 Global

The risk classification results for all GloCorp facilities for 2030 and 2050 are summarized in **Table 5** and **Figure 7**. The results suggest that over the decade centered at 2030 approximate 40% of facilities will experience Low increase in climate risks while ~50 % will experience Medium increase in climate risk with only 10% experiencing High increases in climate risk. However by the decade centered at 2050 only 10% of facilities will experience Low increase in climate risks while ~53 % will experience Medium increase in climate risk but the number experiencing High increase in climate risk will rise to 37%. These results suggest that in the next 10 to 15 years over 60 percent of GloCorp facilities will experience Medium or High increases in climate risks and in 30 to 40 years that number will increase to 90%. The global scale of this risk warrants a closer look at where these risks are most pronounced. The next section will present results by geographical regions.

4.2 Tropical and Extratropical Regions

In this hypothetical example, GloCorp facilities have been distributed across the globe, with 85% of the facilities found in the extratropics (most across the eastern hemisphere), and the remaining 15% are located in the tropical regions (most in the eastern hemisphere). With this prescribed landscape of facilities, we demonstrate below how the risk-triage results can be characterized at regional and at the facility level.

There are 7 facilities are located in the western tropics, and by the 2030 decade, results show no facilities will experience Low increase in climate risks while ~86 % will experience Medium increase in climate risk with 14% experiencing High increases in climate risk. However, by 2050 still no facilities are in the Low classification, and those experiencing Medium increased climate risk drops to 29 % but the number experiencing High increases in climate risk elevate to 71%. This is significantly different from the global results and suggests that the specific facilities in this region face a dramatic increase in climate risks. In the eastern tropics (only 2 facilities), by the 2030 decade results show 100% of the facilities will experience a Low increase in climate risks. By 2050 facilities the two facilities shift from Low to experiencing Medium increased climate risk. These results

Table 4. Example of Total Climate Risk Classification

Facility	Type	Sum of Risk Indices	Total Risk Classification
Manufacturing Facility	Non-Coastal without Ag	12	High

Table 5. Summary Results: Number of Facilities in each Risk Classification

2030					
Risk	**Total**	**E-X**	**E-T**	**W-X**	**W-T**
Low	23	15	0	6	2
Med	32	21	6	5	0
High	5	3	1	1	0
TOTAL	60	39	7	12	2
Low	38%	38%	0%	50%	100%
Med	53%	54%	86%	42%	0%
High	8%	8%	14%	8%	0%
	100%	100%	100%	100%	100%

2050					
Risk	**Total**	**E-X**	**E-T**	**W-X**	**W-T**
Low	6	4	0	2	0
Med	32	22	2	6	2
High	22	13	5	4	0
	60	39	7	12	2
Low	10%	10%	0%	17%	0%
Med	53%	56%	29%	50%	100%
High	37%	33%	71%	33%	0%
	100%	100%	100%	100%	100%

E-X: Eastern Hemisphere Extra Tropical
E-T: Eastern Hemisphere Tropical
W-X: Western Hemisphere Extra Tropical
W-T: Western Hemisphere Tropical

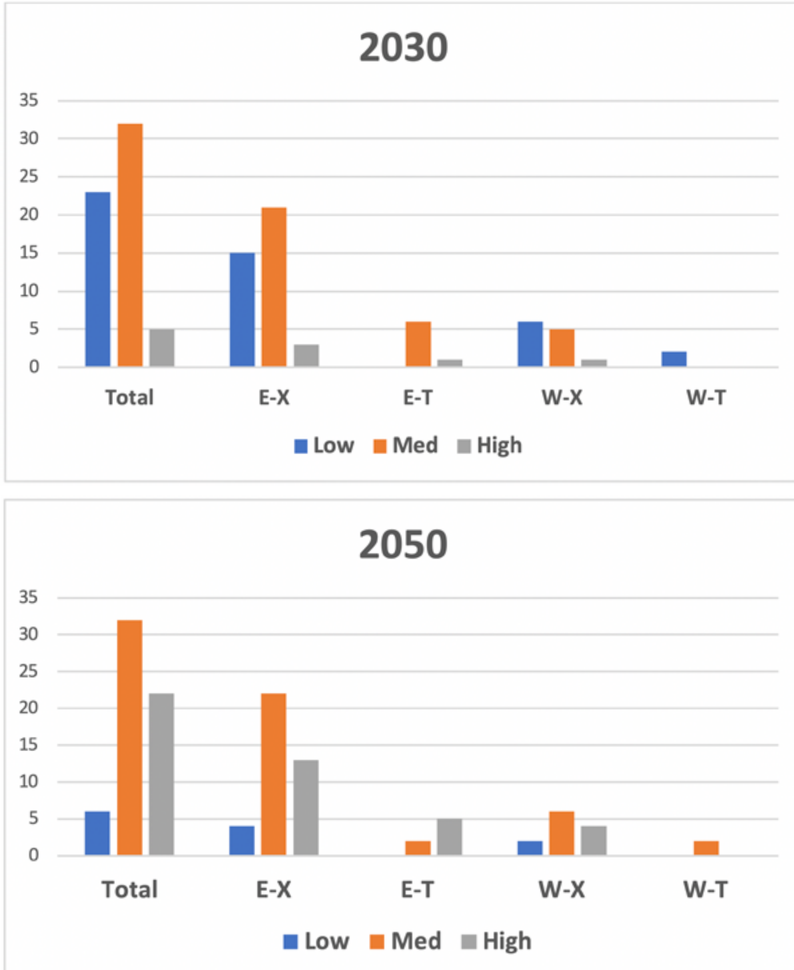

Figure 7. Summary Results

E-X: Eastern Hemisphere Extra Tropical **E-T**: Eastern Hemisphere Tropical
W-X: Western Hemisphere Extra Tropical **W-T**: Western Hemisphere Tropical

are consistent with the global results showing a significant shift of facilities in the Low to the Medium risk.

The eastern extratropics accounts for 65% of GloCorp's facilities. For the decade centered at 2030, 38% of facilities will experience Low increase in climate risks while ~54% will experience Medium increase in climate risk with only 8% experiencing High increases in climate risk. This is very similar to the global results. However by the decade centered at 2050 only 10% of facilities will experience Low increase in climate risks while ~56 % will experience Medium increase in climate risk but the number experiencing High increases in climate risk will increased to 33%. This is similar to the global results with slightly fewer in the High classification.

The western half of the extratropics accounts for 20% of GloCorps facilities with a sample size of 12 facilities. The 2030-decade results show 50% of the facilities will experience Low increase in climate risks while ~42 % will experience Medium increase in climate risk with 8% experiencing High increases in climate risk. However, by 2050 facilities in the Low classification drop to 17% and those in experiencing Medium increased climate risk increase to 50% with the number experiencing High increases in climate risk increasing to 33%. These results are aligned with the global results.

Tables 6-9 present the results across all the risk indicators for 2030 for each facility by the four geographic regions: 1) Eastern- Extra Tropics, 2) Eastern-Tropics, 3) Western- Extra Tropics, and 4) Western-Tropics, respectively. The tables present the classified results for each indictor and for the total risk indicator. **Tables 10-13** detail the results for 2050 for each facility by the four geographic regions. The results show the range of hydroclimatic risks that each facility faces and can be used by corporate risk managers as a tool to identify facilities at high risk as well as to be used corporate infrastructure planners as input to any current site expansions or facilities renovations where adding climate resilience might be warranted.

Table 6. 2030 Eastern Hemisphere Extra Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
1	1	2	2	1	0	0	1	0	2	0	0	0	0	1
2	0	2	2	0	0	0	2	0	1	0	0	1	2	1
3	1	2	2	0	0	0	1	0	2	0	0	1	1	1
4	0	2	0	0	0	0	0	0	1	1	1	2	0	0
5	0	2	2	0	0	0	0	0	1	0	0	1	0	0
6	0	2	0	1	0	0	0	0	2	0	2	2	0	1
9	0	1	0	2	2	0	0	1	2	0	2	1	0	1
13	1	1	0	2	0	0	0	0	0	0	0	2	0	0
15	0	2	2	0	0	0	2	0	1	0	0	0	0	0
19	0	2	2	0	0	0	0	0	0	0	0	1	0	0
20	0	2	2	0	0	0	0	0	1	0	0	1	0	0
23	0	2	0	0	0	0	1	0	0	1	1	2	0	0
24	0	2	1	0	0	0	0	0	1	0	0	1	0	0
25	0	2	2	0	0	0	2	0	1	0	0	0	2	1
26	0	2	2	0	0	0	2	0	1	0	0	1	2	1
27	0	2	2	0	0	0	2	0	1	0	0	1	2	1
28	0	2	2	0	0	0	0	0	1	0	0	0	0	0
30	0	2	1	0	0	0	0	0	1	0	0	2	2	1
32	1	2	2	0	0	0	0	0	1	0	0	0	0	0
34	0	2	0	0	0	0	0	0	1	1	1	2	0	0
35	0	1	2	0	0	0	1	0	1	0	0	1	2	1
36	0	2	2	0	0	0	0	0	0	0	0	0	0	0
37	0	1	1	0	0	0	0	0	1	0	0	1	0	0
39	1	2	2	0	0	0	0	0	0	0	0	1	0	0
40	0	2	1	0	0	0	1	0	1	0	0	2	2	1
43	0	2	0	1	0	0	0	0	0	0	0	2	2	0
44	0	2	2	0	0	0	0	0	0	0	0	1	0	0
45	0	2	1	0	0	0	0	0	0	0	0	1	0	0
46	1	1	0	2	0	0	0	0	0	0	0	2	0	0
48	0	2	1	0	0	0	1	0	2	0	0	2	2	1
49	1	2	0	0	0	0	1	0	0	0	1	2	0	0
50	0	2	2	0	0	0	0	0	1	0	0	1	0	0
51	0	2	1	0	0	0	1	0	1	0	0	2	0	0
52	0	2	2	0	0	0	2	0	1	0	0	0	2	1
54	1	2	2	0	0	0	0	0	2	0	0	1	0	0
56	1	2	2	0	0	0	2	0	1	0	0	0	0	0
57	0	2	1	0	0	0	0	0	0	0	0	1	0	0
58	0	2	0	0	0	0	0	0	1	0	2	2	0	0
59	0	2	2	0	0	0	0	0	1	0	0	1	0	0

CO: Coastal
TMP: Annual Temp
CMI: Climate Moisture Index
MXT: Max Monthly Temp
PRC: Annual Precipitation
PET: Potential Evapotranspiration
IRR: Irrigation Demand
RUN: Annual Runoff
GW: Ground Water Recharge
FLD: Flooding
DRG: Drought
UNC: Uncertainty
EXT: Extreme Events
RISK: Total Risk

Table 7. 2030 Eastern Hemisphere Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
17	1	1	0	2	0	0	1	0	0	1	1	1	2	1
21	1	1	0	1	0	0	0	0	2	0	1	2	2	1
22	1	2	0	2	0	0	1	0	2	0	1	1	0	1
29	0	2	0	2	0	0	2	0	2	0	1	1	0	1
47	1	1	0	2	0	0	0	0	2	0	0	2	0	0
53	1	2	0	2	0	0	2	0	2	1	1	0	0	1
55	1	2	0	2	0	0	2	0	2	0	1	1	0	1

Table 8. 2030 Western Hemisphere Extra Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
7	0	2	1	0	0	1	0	0	1	0	0	1	1	0
8	0	2	0	0	0	1	1	0	1	0	1	2	1	1
11	1	2	1	0	0	0	0	0	1	0	0	0	1	0
12	1	1	1	0	0	0	1	0	0	0	0	1	0	0
14	0	2	2	2	0	0	1	0	1	0	0	2	1	1
16	1	1	0	0	0	0	0	0	1	0	1	2	0	0
18	1	2	1	0	0	0	0	0	1	0	0	1	1	0
31	0	2	1	0	0	0	0	0	1	0	0	0	1	0
33	0	2	1	0	0	0	0	0	1	0	0	0	1	0
38	1	1	1	0	0	0	0	0	0	0	0	1	0	0
41	1	1	0	0	0	0	0	0	2	0	1	2	1	0
60	0	2	1	1	0	0	2	0	1	0	0	2	0	1

Table 9. 2030 Western Hemisphere Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
10	0	1	2	0	0	0	0	0	1	0	0	1	0	0
42	1	1	2	0	0	0	0	0	0	0	0	1	0	0

Table 10. 2050 Eastern Hemisphere Extra Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
1	1	2	2	2	1	0	1	0	2	0	0	0	0	1
2	0	2	2	0	0	0	2	1	2	0	0	1	2	2
3	1	2	2	1	0	0	2	0	2	0	0	1	1	2
4	0	2	0	0	0	0	0	0	2	1	2	1	0	1
5	0	2	2	0	0	1	0	0	2	0	0	1	0	1
6	0	2	0	2	0	1	0	0	2	1	2	2	0	2
9	0	2	0	2	2	0	0	1	2	0	2	1	0	2
13	1	2	0	2	0	0	0	0	2	0	1	2	1	2
15	0	2	2	0	0	0	2	0	2	0	0	0	0	1
19	0	2	2	0	0	1	0	0	1	0	0	0	0	0
20	0	2	2	0	0	1	0	0	2	0	0	1	0	1
23	0	2	0	0	0	0	1	0	1	1	1	2	0	1
24	0	2	2	0	0	1	0	0	1	0	0	1	0	1
25	0	2	2	0	0	0	2	0	2	0	0	0	2	1
26	0	2	2	0	0	1	2	0	1	0	0	0	2	1
27	0	2	2	0	0	0	2	1	2	0	0	1	2	2
28	0	2	2	0	0	1	0	0	2	0	0	0	0	1
30	0	2	2	0	0	0	0	0	2	0	0	1	2	2
32	1	2	2	0	0	1	0	0	2	0	0	0	0	1
34	0	2	0	0	0	0	0	0	2	1	2	1	0	1
35	0	2	2	0	0	0	2	0	2	0	0	1	2	2
36	0	2	2	0	0	1	0	0	0	0	0	0	0	0
37	0	2	2	0	0	0	0	0	2	0	0	1	0	1
39	1	2	2	0	0	1	0	1	1	0	0	1	0	1
40	0	2	1	0	0	0	2	0	1	0	0	2	2	1
43	0	2	0	1	0	0	1	0	1	0	1	2	2	2
44	0	2	2	0	0	1	0	0	0	0	0	1	0	0
45	0	2	2	0	0	1	0	0	1	0	0	1	0	1
46	1	2	0	2	0	0	0	0	1	0	1	2	1	2
48	0	2	1	0	0	0	1	0	2	0	1	2	1	2
49	1	2	0	0	0	1	1	0	1	1	1	2	0	1
50	0	2	2	0	0	1	0	0	2	0	0	0	0	1
51	0	2	2	0	0	1	2	0	2	0	0	2	0	1
52	0	2	2	0	0	1	2	1	2	0	0	0	2	2
54	1	2	2	0	0	1	0	0	2	0	0	1	0	1
56	1	2	2	1	0	0	2	0	2	0	0	1	0	1
57	0	2	2	0	0	1	0	0	0	0	0	0	0	0
58	0	2	0	0	0	1	0	0	2	1	2	2	0	2
59	0	2	2	0	0	1	0	0	2	0	0	1	0	1

Table 11. 2050 Eastern Hemisphere Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
17	1	2	0	2	0	0	2	0	0	1	2	0	2	2
21	1	2	0	1	0	0	0	0	2	0	1	2	2	2
22	1	2	0	2	0	0	2	0	2	0	2	1	0	2
29	0	2	0	2	0	0	2	0	2	0	2	0	0	1
47	1	2	0	2	0	0	0	0	2	0	0	2	0	1
53	1	2	0	2	0	0	2	0	2	2	2	1	0	2
55	1	2	0	2	0	0	2	0	2	1	2	0	0	2

CO: Coastal
TMP: Annual Temp
CMI: Climate Moisture Index
MXT: Max Monthly Temp
PRC: Annual Precipitation
PET: Potential Evapotranspiration
IRR: Irrigation Demand
RUN: Annual Runoff
GW: Ground Water Recharge
FLD: Flooding
DRG: Drought
UNC: Uncertainty
EXT: Extreme Events
RISK: Total Risk

Table 12. 2050 Western Hemisphere Extra Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
7	0	2	2	0	0	1	0	0	2	0	0	1	1	1
8	0	2	0	0	0	1	1	0	2	0	2	2	0	1
11	1	2	1	0	0	1	0	0	2	0	0	1	1	1
12	1	1	1	0	0	0	1	0	0	0	0	1	0	0
14	0	2	2	2	0	0	1	0	2	0	0	2	1	2
16	1	2	0	0	0	0	0	0	1	0	1	2	0	1
18	1	2	1	1	0	1	0	0	2	0	0	1	2	2
31	0	2	1	0	0	1	0	0	2	0	0	1	2	1
33	0	2	1	0	0	1	0	0	1	0	0	1	2	1
38	1	1	1	0	0	0	0	0	0	0	0	0	0	0
41	1	2	0	0	0	0	0	0	2	1	1	2	1	2
60	0	2	1	2	0	0	2	0	2	0	1	2	0	2

CO: Coastal
TMP: Annual Temp
CMI: Climate Moisture Index
MXT: Max Monthly Temp
PRC: Annual Precipitation
PET: Potential Evapotranspiration
IRR: Irrigation Demand
RUN: Annual Runoff
GW: Ground Water Recharge
FLD: Flooding
DRG: Drought
UNC: Uncertainty
EXT: Extreme Events
RISK: Total Risk

Table 13. 2050 Western Hemisphere Tropical Faculties Results

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
10	0	1	2	0	0	0	0	0	1	0	0	1	0	0
42	1	1	2	0	0	0	0	0	0	0	0	1	0	0

4.3 Risk Distribution Across Facilities

The previous sections presented findings focused on the total climate results by geographical region and facility. This section looks at the results by individual hydroclimatic risks that contribute to total climate risk. Drawing from the results in Tables 6-13, **Tables 14 and 15** provide a global summary of the distribution of hydroclimatic risk for 2030 and 2050, respectively. The global summary present for 2030 and 2050, the hydroclimatic risks that are demonstrating the highest increase in risk are Mean Annual Temperature, Climate Moisture Index, GW recharge and Level of uncertainty in Climate Model outputs.

Tables 16-23 provides the same distribution for the four geographical regions for 2030 and 2050. These results show that there is an increase in the magnitude of the hydroclimatic risks from the 2030 to 2050 centered decades. They also show that a subset of indicators provides for the majority of increase globally and regionally. **Table 24** provides a classification of the significance of each hydroclimatic risk indicator globally as well as by the four geographical regions. The table shows that four hydroclimatic indicators: *Mean Annual Temperature, Climate Moisture Index, Groundwater recharge and Model Uncertainty* represent the major threats at the global and regional level. Other hydroclimatic indicators that play an important role in the regions are: The Eastern Hemisphere Extra Tropics- *Sea Level Rise, Maximum Monthly Temperature and Drought;* Eastern Hemisphere Tropics - *Sea Level Rise, Maximum Monthly Temperature, Flooding and Drought*; The Western Hemisphere Extra Tropics – *Potential Evapotranspiration and Extreme Events*; and Western Hemisphere Tropics - *Sea Level Rise, Drought and Extreme Events.*

Table 14. 2030 Summary by Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	63	0	33	75	98	97	60	98	25	92	73	20	65	63
MED	37	23	27	8	0	3	22	2	53	8	22	47	15	37
HIGH	0	77	40	17	2	0	18	0	22	0	5	33	20	0

Table 15. 2050 Summary by Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	63	0	33	70	97	57	58	92	12	83	65	25	63	13
MED	37	7	15	8	2	43	13	8	22	15	17	47	13	50
HIGH	0	93	52	22	2	0	28	0	67	2	18	28	23	37

Table 16. 2030 Eastern Hemisphere Extra Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	77	0	26	85	97	100	62	97	28	92	82	21	72	67
MED	23	13	21	8	0	0	21	3	56	8	10	46	3	33
HIGH	0	87	54	8	3	0	18	0	15	0	8	33	26	0

Table 17. 2050 Eastern Hemisphere Extra Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	77	0	26	79	95	49	59	87	8	85	72	28	67	10
MED	23	0	5	8	3	51	13	13	26	15	15	46	10	56
HIGH	0	100	69	13	3	0	28	0	67	0	13	26	23	33

Table 18. 2030 Eastern Hemisphere Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	14	0	100	0	100	100	29	100	14	71	14	14	71	14
MED	86	43	0	14	0	0	29	0	0	29	86	57	0	86
HIGH	0	57	0	86	0	0	43	0	86	0	0	29	29	0

Table 19. 2050 Eastern Hemisphere Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	14	0	100	0	100	100	29	100	14	57	14	43	71	0
MED	86	0	0	14	0	0	0	0	0	29	14	29	0	29
HIGH	0	100	0	86	0	0	71	0	86	14	71	29	29	71

Table 20. 2030 Western Hemisphere Extra Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	50	0	25	83	100	83	67	100	17	100	75	25	33	75
MED	50	33	67	8	0	17	25	0	75	0	25	33	67	25
HIGH	0	97	52	22	2	0	28	0	67	2	18	32	23	37

Table 21. 2050 Western Hemisphere Extra Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	50	0	25	75	100	50	67	100	17	92	67	8	42	17
MED	50	17	58	8	0	50	25	0	17	8	25	50	33	50
HIGH	0	75	8	17	0	0	0	0	33	0	0	42	25	33

CO: Coastal
TMP: Annual Temp
CMI: Climate Moisture Index
MXT: Max Monthly Temp
PRC: Annual Precipitation
PET: Potential Evapotranspiration
IRR: Irrigation Demand
RUN: Annual Runoff
GW: Ground Water Recharge
FLD: Flooding
DRG: Drought
UNC: Uncertainty
EXT: Extreme Events
RISK: Total Risk

Table 22. 2030 Western Hemisphere Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	50	0	0	100	100	100	100	100	50	100	100	0	100	100
MED	50	100	0	0	0	0	0	0	50	0	0	100	0	0
HIGH	0	0	100	0	0	0	0	0	0	0	0	0	0	0

Table 23. 2050 Western Hemisphere Tropical Risk Indicator: Percent of Facilities in Hydroclimatic Risk Class

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT	RISK
LOW	50	0	0	100	100	100	100	100	50	100	100	0	100	100
MED	50	100	0	0	0	0	0	0	50	0	0	100	0	0
HIGH	0	0	100	0	0	0	0	0	0	0	0	0	0	0

CO: Coastal
TMP: Annual Temp
CMI: Climate Moisture Index
MXT: Max Monthly Temp
PRC: Annual Precipitation
PET: Potential Evapotranspiration
IRR: Irrigation Demand
RUN: Annual Runoff
GW: Ground Water Recharge
FLD: Flooding
DRG: Drought
UNC: Uncertainty
EXT: Extreme Events
RISK: Total Risk

Table 24. Key Hydroclimatic Risks by Geographical

ID	CO	TMP	CMI	MXT	PRC	PET	IRR	RUN	GW	FLD	DRG	UNC	EXT
Global		×××	××			××	×××		××			××	×
E-X	×	×××	××	×		××	×××		×××		×	××	
E-T	××	×××		×××		×	×××		×××	×	×××	×	
W-X		×××	××			×	×		××		×	××	×
W-T	××	×××	×						××		××	××	××

× Some Increased Risk
×× Significantly Increased Risk
××× Severely Increased Risk

5. Insights and Illustrative Recommendations

GloCorp's Global Facilities are facing a growing risk due to climate change impacts. By **2030,** it is projected that 61% of all facilities face a Medium or High Climate Risk. However, as climate change intensifies over the coming century the impact on GloCorp' facilities increases. By **2050,** it is projected that 90% of all facilities face a Medium or High Climate Risk. Regionally, the picture varies somewhat across the regions :

- Eastern Hemisphere Extra Tropics (65% of Facilities) has: 56% Medium; 33% High.
- Eastern Hemisphere Tropics (12% of Facilities) has: 29% Medium; 71% High.
- Western Hemisphere Extra Tropics (20% of Facilities) has: 50% Medium; 33% High.
- Western Hemisphere Tropics (3% of Facilities) has: 100% Medium; 0% High.

The key hydroclimatic threats facing GloCorps facilities are increase in temperature, reduction in water supply, and range of possible magnitude and sign of future risks due to the uncertainty in future GHG emission and uncertainty across global climate models. Some regions will see extreme events in terms of flooding, droughts and heat wave. For coastal facilities, sea level rise and increase in storm surges are a potential threat.

The presented risks across the range of scales in the results section have potential impacts on industrial facilities directly or from the impacts on the local infrastructure, employees and utilities. Such examples include: flood risk, under-designed cooling systems, electricity blackout from overheated transformers, transportation systems carrying employees, inputs and product to market as well local supply chains and even distant supply sources. Data from Canada shows that the average life of industrial facilities is 15 years (Canada, 2019). The results warrant that GloCorp should begin critical consideration into the renovation existing sites or adding new capacity at existing sites or expanding to new sites. This work has shown that climate risks are increasing somewhat by 2030 and significantly by 2050. These risks are relevant to GloCorp's facilities planning process and climate risk should be factored into the planning process. These results suggest a series of more in-depth climate risk assessments are warranted for key GloCorp facilities. The results presented here can assist GloCorp management in prioritizing these local in-depth analyses by combining them with other important information about the critical nature of the research, development and production activities on-going at each facility.

5.1 Insights

GloCorp Global Facilities are facing a growing risk due to climate change impacts.

By **2030,** it is projected that

- 61% of all facilities face a Medium or High Climate Risk with 58% at Medium Risk and 3% at High Climate Risk.

However as climate change intensifies over the coming century the impact on GloCorp' facilities increases.

By **2050,** it is projected that

- 90% of all facilities face a Medium or High Climate Risk with 71% at Medium Risk and 19% at High Climate Risk.

These results suggest a series of more in-depth climate risk assessments are warranted for key GloCorp facilities. The results presented here can assist GloCorp management in prioritizing these local in-depth analyses by combining them with other important information about the critical nature of the research, development and production activities on-going at each facility.

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