Guide to Drought Indices and Indicators Used in North America

May 2021

Commission for Environmental Cooperation

Please cite as:

CEC. 2021. *Guide to Drought Indices and Indicators Used in North America*. Montreal, Canada: Commission for Environmental Cooperation. 62 pp.

This publication was prepared by Ernest W. T. Cooper, Alejandra Peña and Max Winpenny of E. Cooper Environmental Consulting for the Secretariat of the Commission for Environmental Cooperation. The information contained herein is the responsibility of the author and does not necessarily reflect the views of the CEC, or the governments of Canada, Mexico or the United States of America.

ISBN: 978-2-89700-296-1

Disponible en français – ISBN: 978-2-89700-297-8

Disponible en español – ISBN: 978-2-89700-298-5

Legal deposit – *Bibliothèque et Archives nationales du Québec*, 2021

Legal deposit – Library and Archives Canada, 2021

Publication Details

Document category: Project publication

Publication date: May 2021

Original language: English

Review and quality assurance procedures:

Final Party review: April 2021

QA21.360

Project: Operational Plan 2019–2020/ Improving the effectiveness of early warning systems for drought

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List of Abbreviations and Acronyms

CEC	Commission for Environmental Cooperation
CRED	Centre for Research on the Epidemiology of Disasters
GWP	Global Water Partnership
PNP	Percent of Normal Precipitation
SPEI	Standardized Precipitation Evapotranspiration Index
SPI	Standardized Precipitation Index
USDM	United States Drought Monitor
WMO	World Meteorological Organization

Abstract

The objective of this study was to improve the ability of regional and local decision-makers and communities to monitor and prepare for drought conditions through the development of a guide to locally relevant indicators for North American climate regions. Data were collected through an online survey that asked a series of questions on respondents' experiences with drought in their geographical areas. A key series of questions queried the effectiveness of different drought indicators. Responses were analyzed to determine—according to the survey respondents—the most effective drought indicators for short-term and long-term drought in specific North American Köppen climate zones. Online webinars in English and Spanish were held to contribute additional information.

Almost all participants reported their areas of responsibility had experienced drought in the past 10 years, and most indicated that drought was typically less than six months in duration. For most climate zones, respondents indicated that indicators do not perform equally well across their respective geographical areas or across different seasons. Soil Moisture was the only indicator considered to be very effective in every climate zone. Six others were found to be very effective in most, but not all climate zones: Percent of Normal Precipitation, Standardized Precipitation Evapotranspiration Index, Standardized Precipitation Index, Crop Status, Reservoir Storage and the United States Drought Monitor.

The information gathered on the effectiveness of drought indicators was compiled into a series of tables and charts that provide an informal guide to the most appropriate indicators for monitoring drought in North American climate zones.

Executive Summary

In 2016, the World Meteorological Organization (WMO) and the Global Water Partnership (GWP) jointly published the *Handbook of Drought Indicators and Indices*. The handbook is meant to be a reference to the most common drought indicators being used in drought-prone regions around the world. This document is meant to complement the WMO handbook by providing an informal guide to which indicators and indices perform best for monitoring drought in North America. The goal is to improve the ability of regional and local decision-makers and communities to monitor and prepare for drought conditions in North America. This report focuses on the indicators listed in the WMO handbook, along with 22 indicators that were not originally included in the handbook.

The guidance provided in this report is based on opinions gathered from North American drought practitioners via an online survey, supplemented by consultation during two online webinars.

Survey respondents

Out of 145 survey respondents, 84 worked in the United States, 33 worked in Canada and 28 worked in Mexico. Most reported at least 10% of their time was spent on drought monitoring, communications, hazard mitigation or disaster resilience, environmental and natural resources planning, government research, or comprehensive/long-range planning.

Use of drought indicators in North America

Multiple respondents commented that a major factor in choosing indicators was how location-specific they are, and that being able to correlate the indicator with the actual conditions in the field would be desirable. Most survey respondents reported that indicators do not perform equally well across their respective geographical areas of responsibility, or across different seasons. The availability of data was frequently mentioned by survey respondents as a barrier to how well certain indicators function.

Respondents indicated most of the indicators from the WMO handbook were not very effective for most climate zones in North America. Four indicators were considered very effective in most (not all) climate zones, for short- and long-term drought: Percent of Normal Precipitation (PNP), Standardized Precipitation Evapotranspiration Index (SPEI), Standardized Precipitation Index (SPI) and the United States Drought Monitor (USDM). Based on the opinions of survey respondents, SPI and the USDM may be considered the most regionally effective of these drought indicators.

Respondents scored 13 indicators not listed in the WMO handbook as very effective for most climate zones. Soil Moisture was notable as the only indicator scored as very effective in every North American climate zone. Two other indicators—Crop Status and Reservoir Storage—were each scored as very effective for 33 out of 34 climate zones.

Köppen Climate Group A: Tropical Climates

In North America, Köppen climate group A includes the coastal areas of Mexico, southern Florida and the US Virgin Islands. Three drought indicators were scored as very effective for both short- and long-term drought in tropical climate zones: PNP, SPI and the USDM. Survey respondents scored nine drought indicators that were not listed in the WMO Handbook as very effective for monitoring drought in all tropical climate zones. The indicators Vegetation Greenness and Soil Moisture were scored as very effective by large majorities of respondents.

Köppen Climate Group B: Dry (Desert and Semi-arid) Climates

In North America, Köppen climate group B is widespread, covering much of northern Mexico and the western and High Plains regions of the United States into southern areas of western Canada. Two indicators—SPI and the USDM—were scored as very effective for both short- and long-term drought in all dry climate zones. Percent of Normal Precipitation was also scored as very effective for long-term drought in all dry climate zones. Nine indicators that were not listed in the WMO Handbook were scored as very effective for monitoring drought in dry climates. The indicators Reservoir Storage and Soil Moisture were scored as very effective by large majorities of respondents.

Köppen Climate Group C: Temperate Climates

In North America, Köppen climate group C includes areas of central Mexico, the US West Coast and southern Plains to the Southeast, and the West Coast of Canada. Overall, 26 indicators were scored as very effective for monitoring short-term drought in temperate climates. Ten indicators were scored as very effective for long-term drought. The diversity of survey responses and the (relatively) large number of temperate climate zones resulted in a scattered set of results. However, many of the indicators were scored as very effective by only 50% of the respondents.

The USDM was the only indicator that was scored as very effective for short-term drought in all temperate climate zones. Three other indicators were scored as very effective in most (not all) temperate climate zones for short-term drought: PNP, SPEI and SPI. No indicators were scored as very effective for long-term drought in all temperate climate zones. Two indicators—SPI and the USDM-were scored as very effective for most (not all) temperate climate zones for long-term drought. Respondents scored four indicators that were not listed in the WMO Handbook as very effective for monitoring drought in all temperate climate zones. Of these, Reservoir Storage, Crop Status and Soil Moisture were scored very effective by large majorities of respondents.

Köppen Climate Group D: Continental Climates

In North America, Köppen climate group D includes much of the midwestern, northeastern and northwestern parts of the contiguous United States, most of Alaska plus areas of higher elevation. Most of Canada south of the Arctic Circle is within climate group D.

No indicators were scored as very effective for short-term drought in every continental climate zone. The USDM was scored as very effective in all except two climate zones. Three other indicators—PNP, SPEI and SPI—scored well in most continental climate zones. No indicators were scored as very effective for monitoring long-term drought in climate zone Dfd. The USDM scored very effective for long-term drought in all but one climate zone (Dfd). Three other indicators were scored as very effective for long-term drought in *most* continental climate zones: SPEI, PNP and SPI. Survey respondents scored three indicators that were not listed in the WMO Handbook—Crop Status, Precipitation Percentiles and Soil Moisture—as very effective for all continental climate zones.

Köppen Climate Group E: Polar Climates

In North America, Köppen climate group E includes parts of Alaska and higher elevations in the western United States, the Canadian far north, and higher elevations in western Canada. Expertise in these climate zones is restricted to a limited number of authorities.

The USDM was scored as very effective for both short- and long-term drought in both polar climate zones. Survey respondents scored 17 drought indicators that were not listed in the WMO Handbook as very effective for monitoring drought in polar climates. However, given the small number of respondents, it is challenging to draw strong conclusions about the effectiveness of these indicators.

Preface

In 2019, the Council of the Commission for Environmental Cooperation approved the project, *Improving the Effectiveness of Early Warning Systems for Drought*, as part of its Operational Plan for the years 2019-2020. The project consisted of a coordinated effort to improve the effectiveness of early warning systems for drought in North America, through tasks addressing the following three related objectives:

1. Understanding which World Meteorological Organization (WMO) indicators and indices perform best for monitoring drought in North America, in order to improve the ability of regional and local decision-makers and communities to monitor and prepare for drought conditions. This objective was to be addressed through the development of a set of guidelines on the use of locally relevant indicators in North American climate regions.
2. Increasing local capacity to use best practices for preparedness, planning and risk management. This objective was to be addressed by identifying and comparing available drought information and best practices in the three countries and providing recommendations for local communities on how to access and use these drought products and tools, and how to incorporate drought into multi-hazard risk management.
3. Assessing the use of the North American Drought Monitor (NADM), as well as user needs, to inform improvements to the program, including user access and the development of new user-oriented tools, with an emphasis on transboundary regions across North America.

This document is the final product of objective 1.

Acknowledgments

The CEC wishes to thank the following individuals and organizations for their leadership and guidance as members of the steering committee for this project:

- Barrie Bonsal, Environment and Climate Change Canada
- Brian Fuchs, National Drought Mitigation Center, United States
- Elizabeth Weight, NOAA National Integrated Drought Information System, United States
- Javier Vicente Aguilar Lara, *Secretaría de Agricultura y Desarrollo Rural,* Mexico [Secretariat of Agriculture and Rural Development (Sader, formerly Sagarpa)]
- Juan Bernardo Orozco Sánchez, Secretariat of Agriculture and Rural Development, Mexico
- Leticia Albarrán Mena, Secretariat of Agriculture and Rural Development, Mexico
- Mark Shafer, University of Oklahoma, United States
- Meredith Muth, NOAA Oceanic and Atmospheric Research, United States
- Reynaldo Pascual, National Water Commission and National Meteorological Service, Mexico
- Richard R. Heim Jr., NOAA National Centers for Environmental Information, United States
- Shannon Burke, American Planning Association, United States
- Sol Ortiz, Secretariat of Agriculture and Rural Development, Mexico
- Trevor Hadwen, Agriculture and Agri-Food Canada
- Víctor Manuel Rodríguez Moreno, *Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias,* Mexico (National Institute for Research in Forestry, Agriculture, and Livestock, Inifap)

The CEC also acknowledges the staff of the CEC Secretariat’s Environmental Quality Unit involved in ensuring the success of this project: Orlando Cabrera-Rivera, head of unit; Nayheli Alliu, project lead and Erika Hercules, administrative assistant.

Introduction

In 2016, the WMO and the Global Water Partnership (GWP) jointly published the *Handbook of Drought Indicators and Indices*.[1] The purpose of the handbook was to support drought management policies and preparedness plans by discussing and describing the most common drought indicators being used in drought-prone regions. The handbook was designed to be used by drought practitioners as a reference, showing which drought indicators were available and being utilized around the world. The handbook does not rank the different indicators or provide recommendations on which indicators should be used (WMO & GWP, 2016).

This document is meant to complement the WMO handbook by providing guidance as to which drought indicators are the most appropriate for monitoring drought in North American Köppen climate zones. The study focused on the indicators listed in the WMO handbook, but also incorporates 21 indicators that were not included in the handbook. Hence, this report offers an update to the original WMO list of indicators. The guidance provided in this report is based on the opinions gathered from North American drought practitioners. It is an informal guide and not meant to be prescriptive. It is hoped the information provided may be used by decision-makers and communities to help monitor and prepare for drought conditions in their geographic areas of interest, responsibility or residence.

The Köppen climate classification was created by W. P. Köppen in 1884 and revised in collaboration with Rudolf Geiger in the 1930s (and is often referred to as the Köppen-Geiger climate classification). It has subsequently been modified by other climatologists and is currently the most widely accepted global climate classification. Beck et al. (2018) published high-resolution global maps of the Köppen-Geiger climate classification. The Köppen climate classification arranges climates into five major groups and 30 zones (sub-types), based on mathematically defined values for, and seasonality of, monthly air temperature and precipitation (Beck et al., 2018). Each group and zone is represented by a combination of letters. The main climate groups are tropical (A), dry (B), temperate (C), continental (D) and polar (E). Sub-types are defined using additional letters which further describe temperature and precipitation characteristics such as seasonality and extremes.

Users of this guide may select the Köppen climate group and zone(s) relevant to their geographic area of interest or responsibility, and then review the appropriate tables for guidance on which indicators are considered the most effective, based on the opinions of North American drought experts.

This report is divided into five parts. This introduction concludes Part 1. Part 2 describes the methods used to complete the study. Part 3 summarizes the information about respondents to a survey of drought practitioners conducted by the Commission for Environmental Cooperation (CEC). Part 4 provides results from the survey and summarizes the effectiveness of drought indicators by climate group. Part 5 explores the effectiveness and performance of indicators from a North American-wide perspective. The full complement of Köppen climate zones is described in Appendix A, the indicators reviewed for this study are listed in Appendix B, and the questions asked in the online survey are in Appendix C.

[1] Indicators are variables or factors used to describe drought conditions. Indices are computed numerical representations of drought severity that are meant to measure the qualitative state of droughts over a given period of time. Technically, indices are also considered indicators (WMO & GWP, 2016). Hence, for the purposes of this document, the term *drought indicators* is used throughout to refer to both indices and indicators.

Methods

The information in this report was primarily compiled through online surveys and follow-up online group consultations, supplemented via literature review and discussion with relevant experts and stakeholders.

Survey design and distribution

An online survey was created using the design platform Zoho Survey. Survey questions were developed by the project consultants in close consultation with CEC staff and the project Steering Committee.[2] A total of 41 questions were posed in the survey (see Appendix C). Some sought to gather background information (e.g., "In which country do you currently work?") while most were more substantive and targeted the experience and expertise of the survey respondents regarding drought indicators. The final survey was translated and made available in English, French and Spanish—all of which could be accessed using the same survey link.

Invitations to the survey were sent by the CEC via email to 276 potential respondents (205 in English, 17 in French and 54 in Spanish) on 26 March 2020. Recipients were encouraged to forward the survey link to colleagues who were active in drought monitoring. The survey was active for 17 weeks and closed on 23 July 2020. Weekly reports were generated via Zoho Survey to monitor the progress of the survey.

Survey analysis

Analysis was completed using a combination of Zoho and Microsoft software. Survey respondents were not required to answer every question. Hence, the number of responses varies between questions.

Where appropriate, "cross-tab" reports were generated by the Zoho survey platform that compared the data for two separate questions. For example, question 1 asked "In which country do you currently work?" and question 19 asked "Do you currently use the WMO *Handbook of Drought Indicators and Indices* in your work?" A cross-tab report allowed the responses to be compared to provide answers for question 19, sorted by country.

A key question in the survey asked respondents to indicate which Köppen climate zone(s) applied to their geographical area(s) of responsibility. This allowed cross-tab reports to be generated that compared the selected Köppen climate zones to the responses to other questions. This, in turn, allowed the responses to those questions to be summarized based on Köppen climate zones.

Respondents were asked to score a range of drought indicators from "less effective" to "very effective" in relation to their geographical areas of responsibility. This question was asked separately for five categories of indicators: meteorology, soil moisture, hydrology, remote sensing, and composite or modeled. Each category of indicators was presented twice: once to determine their effectiveness for short-term drought, and again for long-term drought.[3] Hence, respondents were asked to complete 10 questions on this topic. The indicators listed in these questions were all taken from the WMO Handbook.

In a related but separate question, respondents were asked to score a list of indicators that were not included in the WMO handbook. All told, survey respondents were asked to provide input as to

[2] The project Steering Committee was comprised of representatives of the governments of Canada, Mexico and the US. The names and affiliations of the Steering Committee are listed in the acknowledgements of this document.

[3] Short-term drought was defined as drought lasting less than six months. Long-term drought was drought that lasted six months or more.

the effectiveness of 73 separate drought indicators, including 51 listed in the WMO Handbook and 22 not listed in the handbook.

The resulting data provided the percentage of respondents from each climate zone that scored each indicator from 1 (less effective) to 5 (very effective). The data for scores of 4 and 5 were then totaled, to provide the percentage of respondents that considered the indicator to be “very effective.”

These data were compiled into tables that may be used to determine the most effective indicators (according to the survey respondents) for short-term and long-term drought in specific North American Köppen climate zones. Only those indicators rated 4 or 5 by 50% or more of the respondents were included in the tables. Blank cells in the tables indicate that less than 50% rated the indicator as very effective.

Consultation design and distribution

Two webinars (online seminars) were facilitated to gather more in-depth information about topics related to drought and the use of drought indicators in North America. The content of both webinars was identical except for language—one was held in English and one in Spanish.

Discussion topics and questions were based on analysis of the results of the online project survey. Questions were initially designed by the consulting team and revised through consultation with CEC staff and the project Steering Committee. Each webinar focused on a series of questions by discussion topic. The discussion topics and questions were as follows:

1. Defining drought:
    a. How do you define drought in your geographic area of responsibility or economic sector?
    b. How does drought affect people in your geographic area of responsibility?
2. Climate zones:
    a. Are there unique aspects of climate in your area that you feel might be relevant to drought monitoring or the application of specific drought indices?
3. Drought indicators:
    a. How effective are drought indicators for your area or sector?
    b. How can the available indicators be improved—what specific features are lacking, or what additional data could be collected?
4. Percent of Normal Precipitation (PNP):
    a. For those who use PNP, why is this drought index important, compared to other indicators?
    b. How does PNP help you understand drought?
    c. How familiar are you with the difference in effectiveness between the drought indicators PNP and Standardized Precipitation Index (SPI)?

After completion of the consultation design, invitations were distributed via email by the CEC to contacts compiled with the Steering Committee. The invitations included a link to a Zoho survey via which participants could provide their contact information. Participants were subsequently sent Internet links and passwords via email.

Consultation process

The webinars took place virtually using the Zoom video conferencing platform. The English webinar was held on October 8, 2020, and the Spanish webinar was held on October 13, 2020. The three-hour webinars were facilitated by the consultants. The content of the webinars consisted of introductory presentations by the CEC and consultant team, followed by the discussion led by expert members of the

Steering Committee. Participants were encouraged to join the dialogue verbally or by writing in the chat forum. The webinars were recorded, and the chat content was copied for future reference.

Survey respondents

Country

Survey respondents were asked in which country they worked. Out of the 145 that answered the question, 84 worked in the United States, 33 worked in Canada and 28 worked in Mexico.

Sectors

Most survey respondents (65%) reported they had an official role in drought management. (Table 1 and Fig. 1). When asked what their roles were, the majority (91%) indicated they have a role in some level of government. Of these, 46% indicated they play a role in federal government and 26% play a role in state or provincial government. A total of 16% play a role in city or regional water management, city or municipal emergency management or public safety, or other city or local government role. An additional 3% have a role in Indigenous government (Table 1 and Fig. 1).

Approximately one-fifth (21%) of respondents had a role in academia or research. A total of 13% had a role in nongovernmental or intergovernmental organizations. Fifteen percent had a role in the private sector, either as an agricultural producer, in a trade or professional association, or other private sector or business (Table 1 and Fig. 1).

Few respondents indicated they had a role in media (4%) or as a community or urban planner. Ten percent reported they had an "other" role, including "international organization," "Conservation Authority (watersheds)," and "recently retired" (Table 1 and Fig. 1).

Activities

Survey respondents were asked how much time they spent on drought-related activities. Most survey respondents reported at least 10% of their time was spent on the following activities: drought monitoring (84% of respondents), communications (69%), hazard mitigation or disaster resilience (66%), environmental and natural resources planning (61%), government research (59%) and comprehensive/long-range planning (51%) (Table 2 and Fig. 2).

Table 1. Survey Respondents' Roles in Relation to Drought

Role	Responses
City or regional water management	9
City/municipal emergency management or public safety	3
Academia or research	17
Other city or local government representative	1
Indigenous government	2
Private sector/business	3
Agricultural producer (farmer, rancher, etc.)	8
Trade or professional association	1
Nongovernmental organization	2
Intergovernmental organization	8
Media	3
State or provincial government	21
Federal government	37
Community or urban planner	1
Other	8

Note: Respondents could report having multiple roles.

Figure 1. Survey Respondent Roles in Relation to Drought, by Percent

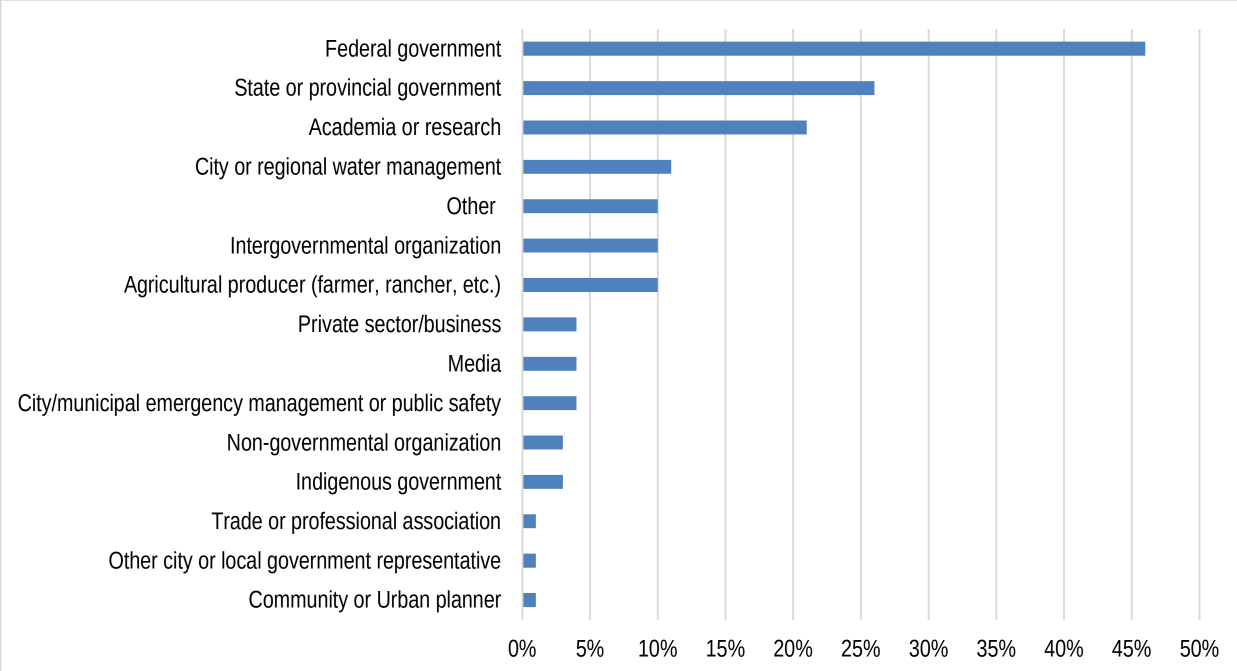
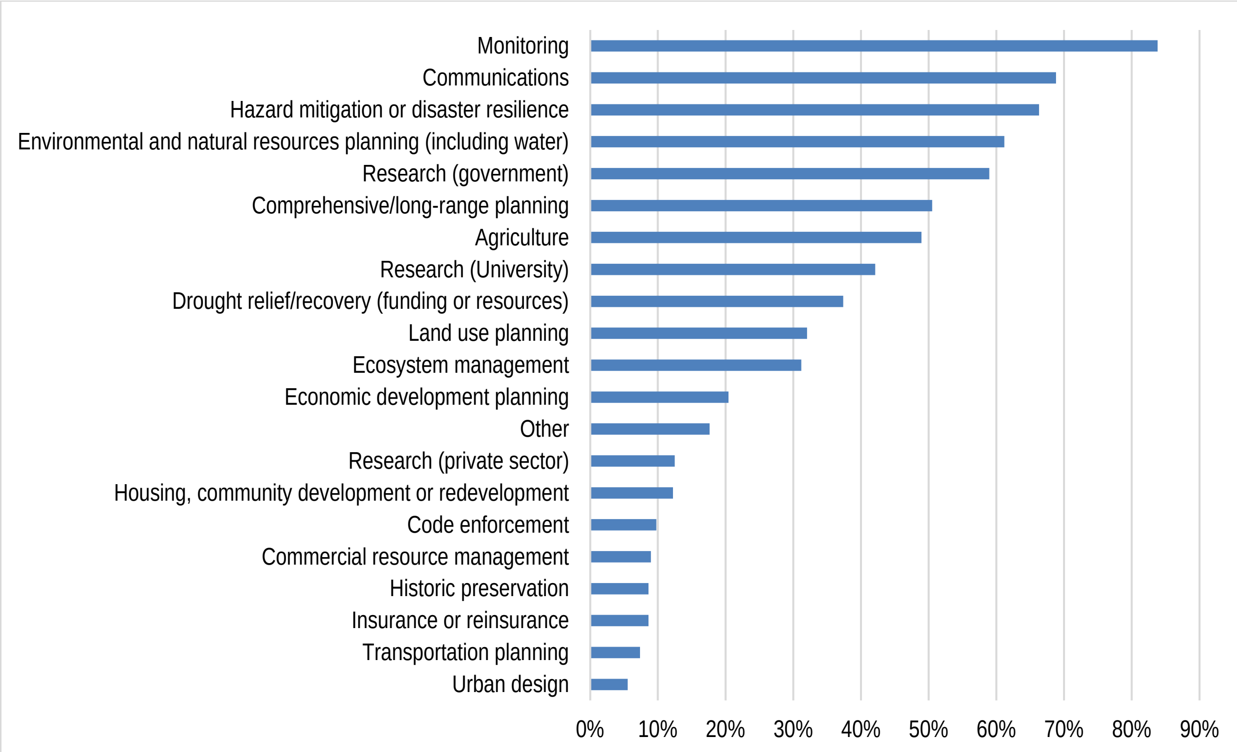


Table 2. Respondent Drought-related Activities

Activities	Responses
Agriculture	46
Code enforcement	9
Commercial resource management	8
Communications	64
Comprehensive/long-range planning	49
Drought relief/recovery (funding or resources)	34
Economic development planning	19
Ecosystem management	29
Environmental and natural resources planning (including water)	63
Hazard mitigation or disaster resilience	63
Historic preservation	8
Housing, community development or redevelopment	12
Insurance or reinsurance	8
Land-use planning	33
Monitoring	83
Research (government)	56
Research (private sector)	11
Research (university)	40
Transportation planning	7
Urban design	5
Other	9

Note: Responses indicate the number of survey respondents that reported spending 10% or more of their time on the respective activities. Respondents could select multiple activities.

Figure 2. Survey Respondent Drought-related Activities, by Percent



Drought indicators by Climate Group

Köppen Climate Group A: Tropical Climates

Drought in North American tropical climates

Climate group A is defined as tropical climates with temperatures in the coldest months of at least 18°C. There are three climate zones in the group, based on the seasonal precipitation type (Heim, in litt.; Peel, Finlayson, & McMahon, 2007):

- Af: Tropical Rainforest
- Am: Tropical Monsoon
- Aw: Tropical Savanna

In North America, Köppen climate group A is restricted to southern and coastal areas of Mexico, southern Florida and the US Virgin Islands (Fig. 3). Of the 164 survey responses, 49 respondents reported their geographic area of responsibility included Köppen climate group A. This included 18 for climate zone Af, 12 for climate zone Am and 19 for climate zone Aw. Most of these respondents reported they had an official role in drought management, including 12 for climate zone Af, 8 for climate zone Am and 10 for climate zone Aw.

One respondent was from Canada, 15 from Mexico and 33 from the United States. The US responses included some from US-Affiliated Pacific Islands (in Micronesia and American Samoa) representing Af and Aw climate zones (Table 3).

All of the respondents in climate zones Af and Am, and all but one respondent in climate zone Aw indicated their areas of responsibility had experienced drought in the past 10 years (Table 4). Most respondents for all three tropical climate zones reported drought had occurred in three to five years out of the past 10 (Table 5).

Typical drought durations ranged from one to more than 12 months long. No respondents reported drought that lasted less than one month in any group A climate zone. Most respondents indicated droughts typically lasted six months or less in each climate zone and would therefore be considered short-term (Table 6 and Fig. 4). Most reported a typical drought lasted for three to six months.

Factors affecting choice of indicators

Most survey respondents indicated the relevance of the indicator, availability of relevant and required data, and familiarity with the indicator were all very important factors for choosing indicators in tropical climates. The history of indicators used previously in the area or region was perceived as very important for most respondents from climate zones Af and Am, and the complexity or difficulty of the required calculation was considered very important for most respondents from climate zone Am (Table 7).

The most important factors when choosing indicators in tropical climates listed in order of importance (from most to least), were as follows:

- Relevance of the indicator to the area or region
- Availability of relevant and required data to calculate the indicator
- Familiarity with the specific indicator
- The history of indicators used previously in the area or region
- Complexity or difficulty of the required calculation

Performance of indicators

The opinions of survey respondents were approximately evenly split as to whether indicators performed equally well across their respective geographical areas of responsibility in tropical climate zones (Table 8, Fig. 5). In contrast, most respondents reported indicators did perform equally well across different seasons in tropical climate zones (Table 9, Fig. 6).

Drought indicators in North American tropical climates

Overall, 50% or more of the respondents scored 12 different indicators as very effective for short-term drought in tropical climates. Seven indicators were scored as very effective for long-term drought (Table 10). However, many of the indicators were scored as very effective by only 50% of the respondents. Hence, half of respondents did not consider these indicators to be very effective.

Three indicators were scored as effective in all three climate zones for both short-term and long-term drought: PNP, SPI and the United States Drought Monitor (USDM). These three indicators may be considered the most effective for monitoring drought in North American Tropical Climates. It is worth noting that SPI scored highly with more respondents than PNP for most tropical climate zones, especially for monitoring long-term drought (Table 10).

Survey respondents scored 18 drought indicators that were not listed in the WMO Handbook as very effective for monitoring drought in tropical climates. Nine were scored as very effective for all three tropical climate zones. Vegetation Greenness and Soil Moisture were scored as very effective by an average of 82% and 75% of the respondents (respectively) in the three tropical climate zones. Reservoir Storage was scored highly for climate zones Af and Am, but less so for climate zone Aw (Table 11).

Figure 3. Distribution of Tropical Climates in North America

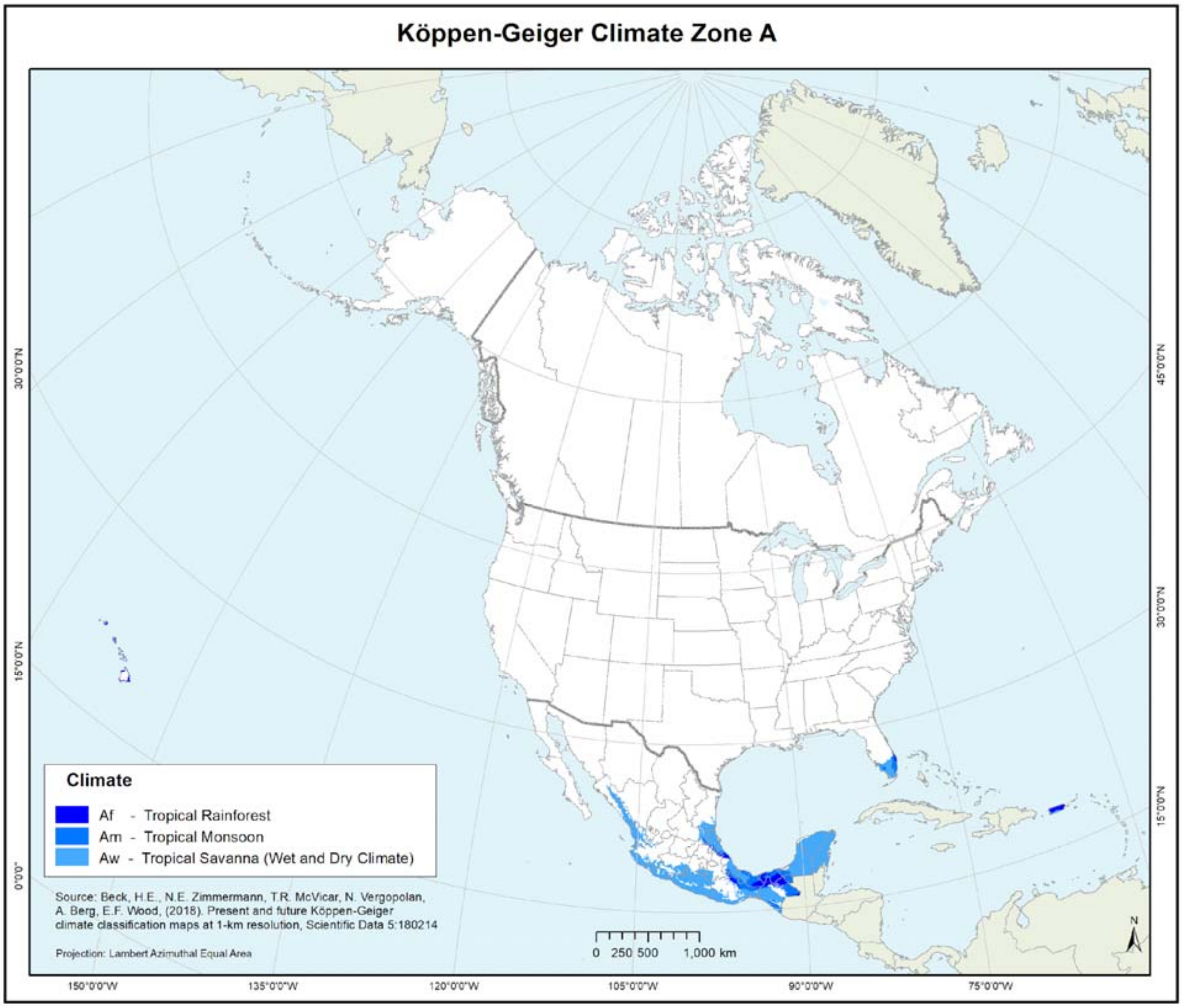


Table 3. Survey Respondents Active in Tropical Climates, by Country

Climate Zone	Canada	Mexico	United States	Total
Af: Tropical Rainforest	-	5	13	18
Am: Tropical Monsoon	-	4	8	12
Aw: Tropical Savanna	1	6	12	19
Total	1	15	33	49

Note: Data indicate the number of survey responses.

Table 4. Occurrence of Drought in Tropical Climates, in the Past 10 years

Climate Zone	Yes	No	Do not know
Af: Tropical Rainforest	18	-	-
Am: Tropical Monsoon	12	-	-
Aw: Tropical Savanna	18	1	-
Total	48	1	-

Note: Data indicate the number of survey responses.

Table 5. Frequency of Drought in Tropical Climates

Climate Zone	Drought frequency (years)		
	1 – 2	3 – 5	5+
Af: Tropical Rainforest	4	8	6
Am: Tropical Monsoon	2	6	4
Aw: Tropical Savanna	4	8	6
Total	10	22	16

Note: Data indicate the number of survey responses. Drought frequency refers to how often drought was experienced in the past 10 years.

Table 6. Duration of Typical Drought in Tropical Climates

Climate Zone	Drought duration (months)				Short-term drought	Long-term drought
	1 – 3	3 – 6	6 – 12	12+		
Af: Tropical Rainforest	3	9	2	3	12	5
Am: Tropical Monsoon	1	8	1	1	9	2
Aw: Tropical Savanna	3	12	1	2	15	3
Total	7	29	4	6	36	10

Note: Data indicate the number of survey responses, which differed for long-term drought and short-term drought. Short-term drought is less than six months in duration. Long-term is six months or more in duration.

Figure 4. Duration of Typical Drought in Tropical Climates: Short- vs. Long-term

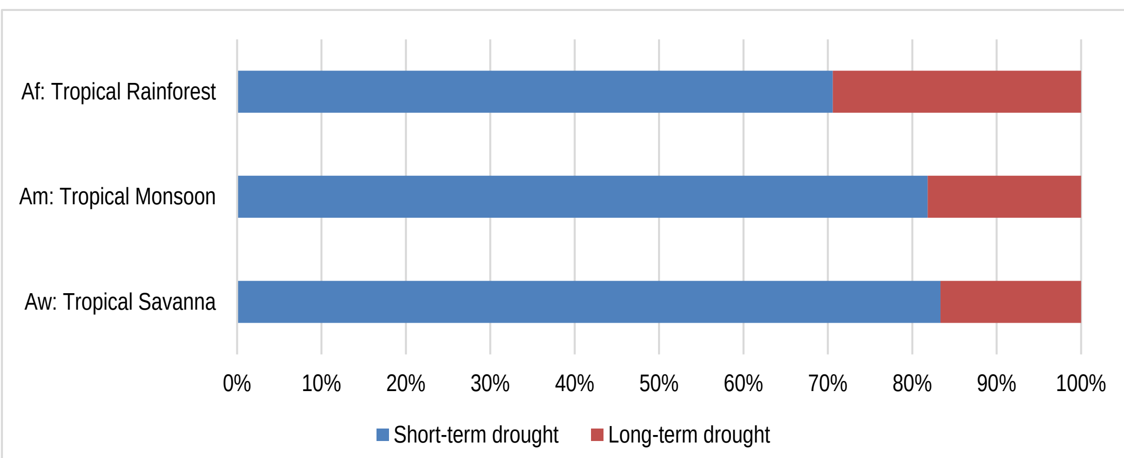


Table 7. Factors Affecting Choice of Indices and Indicators in Tropical Climates

Factors	Köppen Climate Zone		
	Af	Am	Aw
Availability of required data to calculate the indicator	64%	56%	57%
Complexity or difficulty of the required calculation	-	56%	-
Relevance of the indicator to the area/region	64%	67%	64%
Familiarity with the specific indicator	55%	56%	50%
History of indicators used previously in the area or region	55%	56%	-
Number of responses	11	9	14

Note: Data indicate where at least 50% of the survey respondents scored the factor as very important for the respective climate zone. Af (Tropical Rainforest); Am (Tropical Monsoon); Aw (Tropical Savanna – Wet and Dry Climate).

Table 8. Performance of Indicators Across Geographical Area in Tropical Climates

Climate Zone	Indices and indicators perform equally well	Indices and indicators do not perform equally well
Af: Tropical Rainforest	6	5
Am: Tropical Monsoon	4	5
Aw: Tropical Savanna	7	7
Total	17	17

Note: Data indicate the number of survey responses.

Table 9. Performance of Indicators Across Different Seasons in Tropical Climates

Climate Zone	Indices and indicators perform equally well	Indices and indicators do not perform equally well
Af: Tropical Rainforest	7	4
Am: Tropical Monsoon	5	4
Aw: Tropical Savanna	9	5
Total	21	13

Note: Data indicate the number of survey responses.

Figure 5. Do Indicators Perform Equally in Geographical Areas of Tropical Climates?

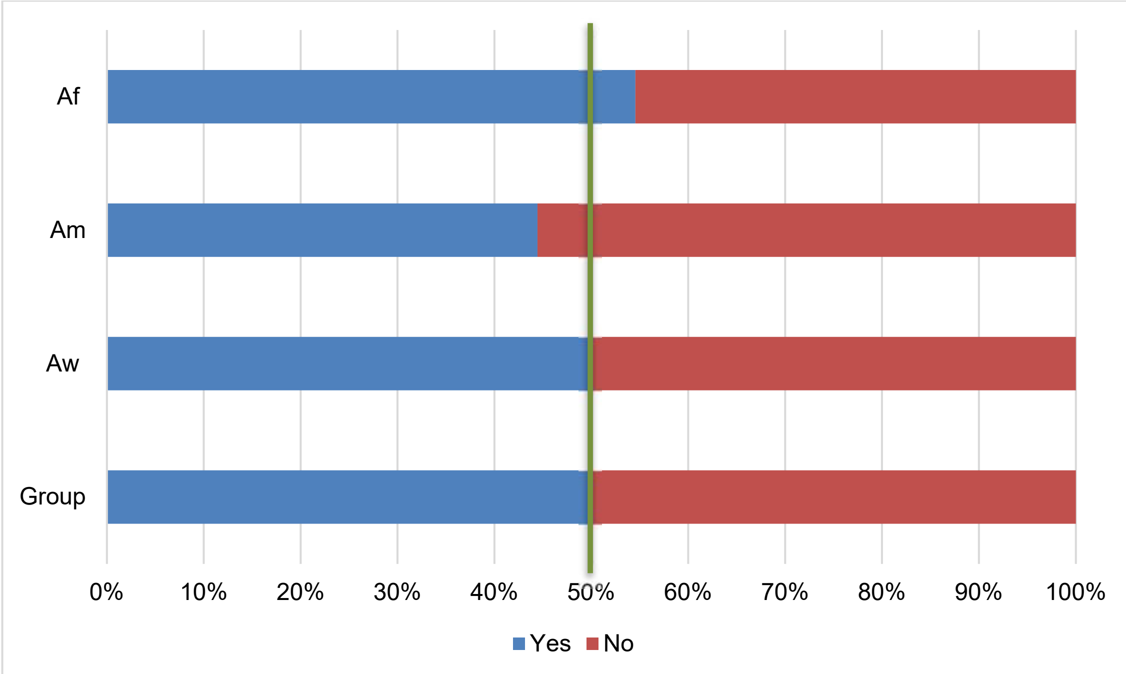


Figure 6. Do Indicators Perform Equally in Different Seasons in Tropical Climates?

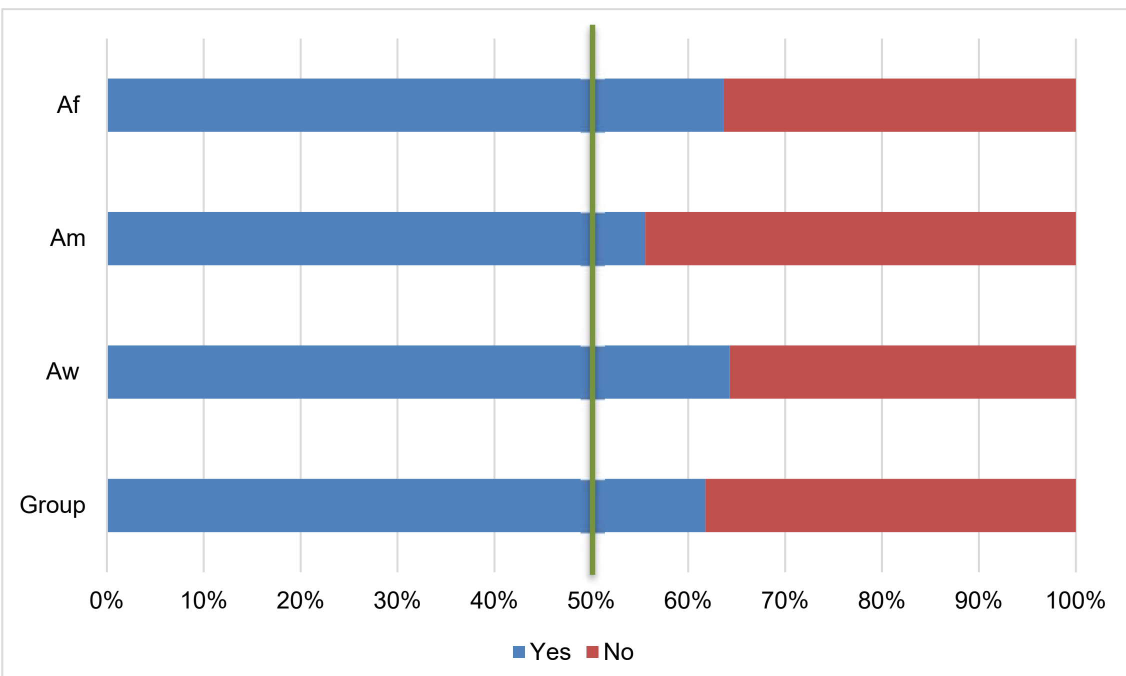


Table 10. Most Effective Indices and Indicators for Drought in Tropical Climates

(a) Most effective indicators for *short-term* drought in tropical climates

Category	Indicator	Köppen Climate Zone		
		Af	Am	Aw
Meteorology	Crop Moisture Index	-	50%	-
	Percent of Normal Precipitation	57%	60%	56%
	Standardized Anomaly Index	-	50%	-
	Standardized Precipitation Evapotranspiration Index	-	50%	-
	Standardized Precipitation Index	64%	70%	50%
	Weighted Anomaly Standardized Precipitation	-	50%	-
	Number of responses	14	10	16
Soil moisture	Soil Moisture Anomaly	50%	50%	-
	Soil Moisture Deficit Index	50%	60%	-
	Number of responses	12	10	15
Remote sensing	Enhanced Vegetation Index	50%	50%	-
	Evaporative Stress Index	50%	50%	-
	Normalized Difference Vegetation Index	58%	60%	-
	Number of responses	12	10	15
Composite or modeled	United States Drought Monitor	75%	70%	67%
	Number of responses	12	10	15

(b) Most effective indicators for *long-term* drought in tropical climates

Category	Indicator	Köppen Climate Zone		
		Af	Am	Aw
Meteorology	Effective Drought Index	-	50%	-
	Palmer Drought Severity Index	50%	50%	-
	Percent of Normal Precipitation	50%	50%	57%
	Standardized Precipitation Evapotranspiration Index	-	50%	-
	Standardized Precipitation Index	83%	88%	57%
	Weighted Anomaly Standardized Precipitation	-	50%	-
	Number of responses	12	8	14
Composite or modeled	United States Drought Monitor	64%	67%	64%
	Number of responses	11	9	14

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Short-term drought is less than six months in duration. Long-term is six months or more in duration. Af (Tropical Rainforest); Am (Tropical Monsoon); Aw (Tropical Savanna – Wet and Dry Climate).

Table 11. Most Effective Indices and Indicators for Drought in Tropical Climates *not* listed in the WMO *Handbook of Drought Indicators and Indices*

Indicator	Köppen Climate Zone		
	Af	Am	Aw
5-day Forecasts	70%	63%	-
8 to 14-day Forecasts	50%	-	-
Crop Status	70%	75%	-
Groundwater Depth	70%	75%	54%
Precipitation Departures from Normal	70%	63%	62%
Precipitation Percentiles	70%	75%	62%
Precipitation Ranks	60%	63%	-
Reported Drought Impacts	70%	63%	-
Reservoir Storage	80%	75%	62%
Seasonal Forecasts	50%	50%	-
Soil Moisture	80%	75%	69%
Streamflow	60%	50%	-
Temperature Departures from Normal	60%	63%	62%
Temperature Ranks	60%	63%	-
Vegetation Greenness	90%	88%	69%
Water Quality	-	50%	-
Water Use/Demand	60%	63%	54%
Wildfire Locations/Reports	60%	50%	54%
Number of responses	10	8	13

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Af (Tropical Rainforest); Am (Tropical Monsoon); Aw (Tropical Savanna – Wet and Dry Climate).

Köppen Climate Group B: Dry (Desert and Semi-arid) Climates

Drought in North American dry climates

Climate group B is characterized by the lack of precipitation. There are six climate zones in the group, based on the seasonal precipitation type and annual mean temperature, as follows (Heim, in litt.; Peel, Finlayson, & McMahon, 2007):

- BW: Arid (desert)
- BWh: Hot Desert Climate
- BWk: Cold Desert Climate
- BS: Semi-arid
- BSh: Hot Semi-arid Climate
- BSk: Cold Semi-arid Climate

Köppen climate group B is widespread in North America, covering much of northern Mexico, and the western and High Plains regions of the United States into southern areas of western Canada (Fig. 7). Of the 164 survey responses, 133 respondents reported their geographic area of responsibility included Köppen climate group B. Respondents' areas of responsibility were distributed amongst all of the climate zones, with the highest proportion being BSk, which accounted for 28% of all the respondents for climate group B. Thirteen respondents were from Canada (primarily climate zone BSk), 32 from Mexico and 88 from the United States (Table 12).

Almost all of the dry climate group respondents indicated their area of responsibility experienced drought in the prior 10 years. Two reported they had not experienced drought in climate zone BSk and three indicated they did not know (Table 13).

Most respondents reported drought had occurred in more than five years out of the past 10 (Table 14). This suggests that (at the time of writing) in the past 10 years, many areas with dry climates in North America experienced drought in more years than they did not.

Typical drought duration ranged from one to more than 12 months. No respondents reported drought that lasted less than one month in any of the group B climate zones. The majority of respondents in each climate zone *except* BW indicated droughts typically lasted six months or more and would therefore be considered long-term. For climate zone BW, responses were split, with seven indicating drought typically lasted less than six months (short-term), and six indicating drought typically lasted six months or longer (long-term) (Table 15 and Fig. 8).

Factors affecting choice of indicators

The availability of relevant and required data was the most important factor when choosing indicators for dry climates. This was particularly true for climate zones BW, BWh, BS and BSh, in which more than 80% of respondents indicated this factor was very important. The relevance of the indicator and familiarity with the indicator was also considered very important by most respondents for all dry climate zones. It is worth noting that more respondents (80%) indicated the relevance of the indicator as very important for climate zone BSk than they did the availability of data (Table 16).

The complexity or difficulty of the required calculation was considered very important for approximately 50% of the respondents from climate zones BW, BWh and BSh. The history of indicators used previously in the area or region was perceived as very important for approximately 60% of respondents from climate zones BS and BSk. (Table 16).

The most important factors when choosing indicators in dry climates, listed in order of importance (from most to least), were as follows:

- Availability of relevant and required data to calculate the indicator
- Relevance of the indicator to the area or region
- Familiarity with the specific indicator
- Complexity or difficulty of the required calculation
- The history of indicators used previously in the area or region

Performance of indicators

Most survey respondents agreed that indicators do not perform equally well across their respective geographical areas of responsibility in dry climate zones (Table 17, Fig. 9). Most respondents also reported that indicators did not perform equally well across different seasons. However, the opinions were closest to evenly split for climate zones BW and BWh (Table 18, Fig. 10).

Drought indicators in North American dry climates

Overall, six indicators were scored as very effective for monitoring short-term drought in dry climates. Four indicators were scored as very effective for long-term drought (Table 19).

Two indicators were scored as very effective for short-term drought in all dry climate zones: SPI and USDM. These were also scored as very effective for long-term drought in all dry climate zones, as was PNP. It is worth noting PNP scored as very effective for short-term drought in climate zones BWk, BS, BSh and BSk (Table 19). SPI and the USDM may be considered the most effective for monitoring drought in North American dry climates.

Fifteen drought indicators that were not listed in the WMO Handbook scored as very effective for monitoring drought in dry climates. Of these, nine scored as very effective for all dry climate zones. Two indicators—Reservoir Storage and Soil Moisture—are notable as they were scored as very effective by an average 80% and 82% of the respondents (respectively). Precipitation Percentiles, Reported Drought Impacts and Streamflow were also scored highly with at least 70% of respondents (on average) scoring them as very effective (Table 20).

Figure 7. Distribution of Dry Climates in North America

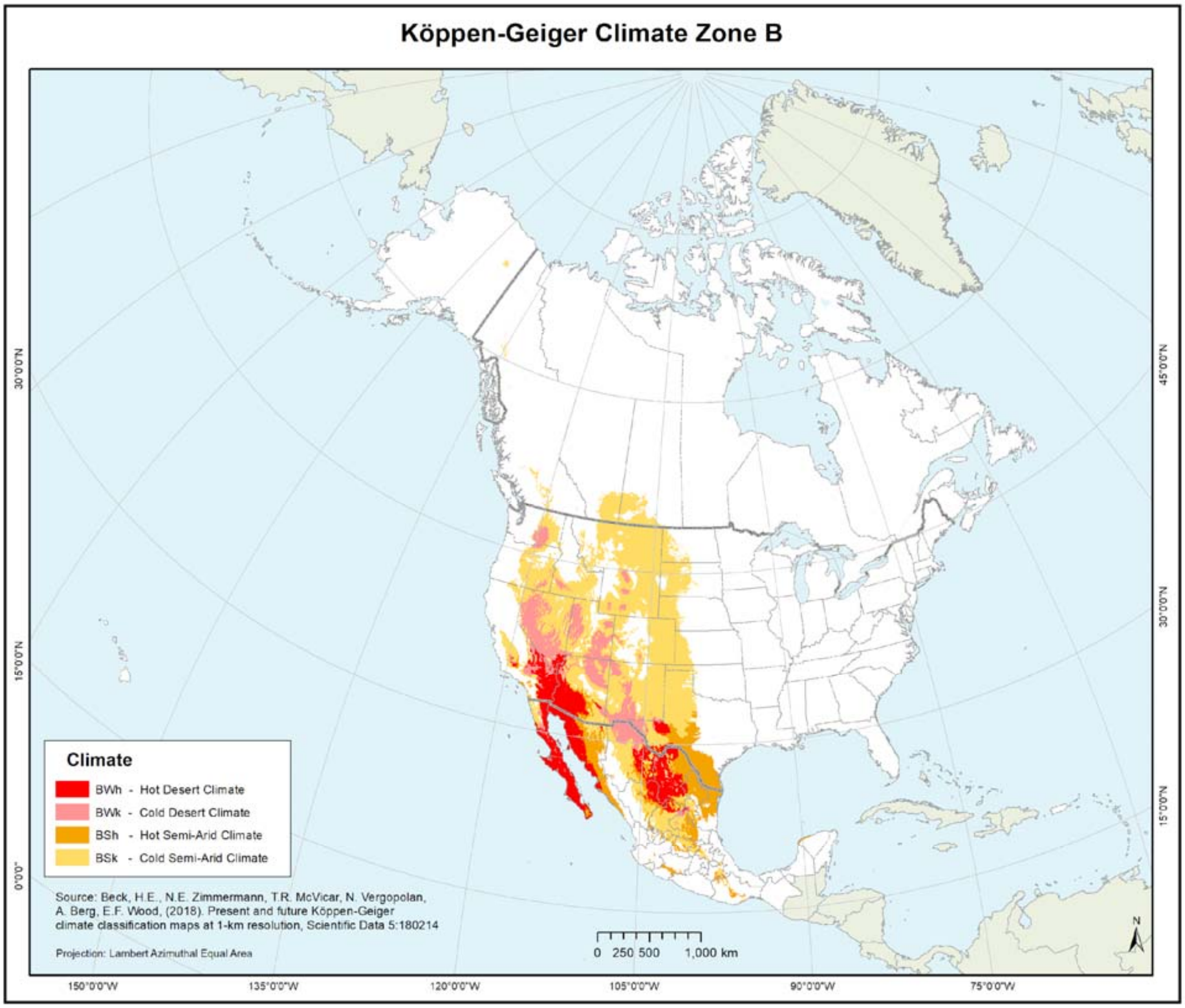


Table 12. Survey Respondents Active in Dry Climates, by Country

Climate Zone	Canada	Mexico	United States	Total
BW: Arid (desert)	-	6	7	13
BWh: Hot Desert Climate	1	5	15	21
BWk: Cold Desert Climate	2	5	19	26
BS: Semi-arid	2	6	11	19
BSh: Hot Semi-arid Climate	-	7	10	17
BSk: Cold Semi-arid Climate	8	3	26	37
Total	13	32	88	133

Note: Data indicate the number of survey responses.

Table 13. Occurrence of Drought in Dry Climates, in the Past 10 years

Climate Zone	Yes	No	Do not know
BW: Arid (desert)	13	-	-
BWh: Hot Desert Climate	21	-	-
BWk: Cold Desert Climate	25	-	1
BS: Semi-arid	18	-	1
BSh: Hot Semi-arid Climate	16	-	1
BSk: Cold Semi-arid Climate	35	2	-
Total	128	2	3

Note: Data indicate the number of survey responses.

Table 14. Frequency of Drought in Dry Climates

Climate Zone	Drought frequency (years)			
	1 – 2	3 – 5	5+	Do not know
BW: Arid (desert)	-	6	7	-
BWh: Hot Desert Climate	-	7	14	-
BWk: Cold Desert Climate	-	8	16	1
BS: Semi-arid	1	6	11	-
BSh: Hot Semi-arid Climate	2	3	11	-
BSk: Cold Semi-arid Climate	4	13	17	1
Total	7	43	76	2

Note: Data indicate the number of survey responses. Drought frequency refers to how often drought was experienced in the past 10 years.

Table 15. Duration of Typical Drought in Dry Climates

Climate Zone	Drought duration (months)				Short-term drought	Long-term drought
	1 – 3	3 – 6	6 – 12	12+		
BW: Arid (desert)	1	6	2	4	7	6
BWh: Hot Desert Climate	2	5	4	9	7	13
BWk: Cold Desert Climate	2	6	6	10	8	16
BS: Semi-arid	2	6	4	6	8	10
BSh: Hot Semi-arid Climate	2	4	4	6	6	10
BSk: Cold Semi-arid Climate	4	10	8	13	14	21
Total	13	37	28	48	50	76

Note: Data indicate the number of survey responses, which differed for long-term drought and short-term drought. Short-term drought is less than six months in duration. Long-term is six months or more in duration.

Figure 8. Duration of Typical Drought in Dry Climates: Short- vs. Long-term

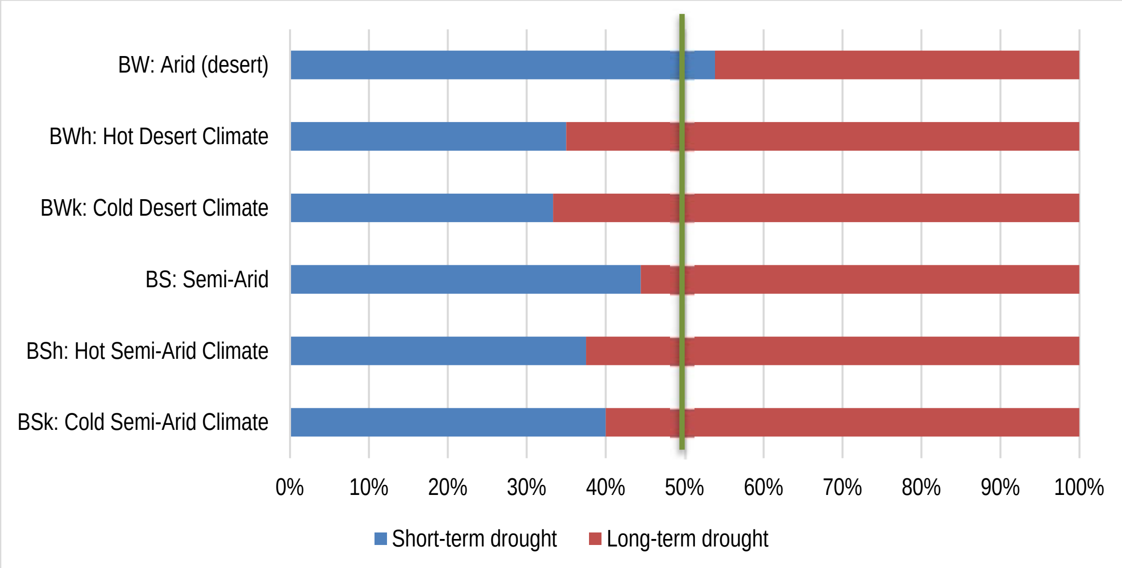


Table 16. Factors Affecting Choice of Indicators in Dry Climates

Factors	Köppen Climate Zone					
	BW	BWh	BWk	BS	BSh	BSk
Availability of required data to calculate the indicator	91%	88%	70%	88%	83%	63%
Complexity or difficulty of the required calculation	55%	53%	-	-	50%	-
Relevance of the indicator to the area/region	73%	76%	75%	81%	75%	80%
Familiarity with the specific indicator	64%	76%	65%	69%	58%	63%
History of indicators used previously in the area or region	-	-	-	63%	-	60%
Number of responses	11	17	20	16	12	30

Note: Data indicate where at least 50% of the survey respondents scored the factor as very important for the respective climate zone. BW (Arid – desert); BWh (Hot Desert Climate); BWk (Cold Desert Climate); BS (Semi-Arid); BSh (Hot Semi-Arid Climate); BSk (Cold Semi-Arid Climate).

Table 17. Performance of Indicators Across Geographical Area in Dry Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
BW - Arid (desert)	2	9
BWh - Hot Desert Climate	5	12
BWk - Cold Desert Climate	5	15
BS - Semi-Arid	4	12
BSh - Hot Semi-Arid Climate	3	9
BSk - Cold Semi-Arid Climate	7	23
Total	26	80

Note: Data indicate the number of survey responses.

Table 18. Performance of Indicators Across Different Seasons in Dry Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
BW - Arid (desert)	5	6
BWh - Hot Desert Climate	8	9
BWk - Cold Desert Climate	7	13
BS - Semi-Arid	7	9
BSh - Hot Semi-Arid Climate	4	8
BSk - Cold Semi-Arid Climate	10	20
Total	41	65

Note: Data indicate the number of survey responses.

Table 19. Most Effective Indices and Indicators for Drought in Dry Climates

(a) Most effective indicators for *short-term* drought in dry climates

Category	Indicator	Köppen Climate Zone					
		BW	BWh	BWk	BS	BSh	BSk
Meteorology	Percent of Normal Precipitation	-	-	60%	50%	50%	59%
	Standardized Precipitation Evapotranspiration Index	54%	55%	-	56%	63%	-
	Standardized Precipitation Index	62%	70%	64%	61%	81%	62%
	Number of responses	13	20	25	18	16	34
Remote sensing	Normalized Difference Vegetation Index	75%	61%	-	50%	58%	-
	Vegetation Drought Response Index	58%	50%	-	-	67%	-
	Number of responses	12	18	21	16	12	31
Composite or modeled	United States Drought Monitor	67%	67%	67%	63%	75%	71%
	Number of responses	12	18	21	16	12	31

(b) Most effective indicators for *long-term* drought in dry climates

Category	Indicator	Köppen Climate Zone					
		BW	BWh	BWk	BS	BSh	BSk
Meteorology	Percent of Normal Precipitation	55%	61%	61%	63%	57%	58%
	Standardized Precipitation Evapotranspiration Index	55%	-	-	50%	57%	-
	Standardized Precipitation Index	64%	67%	65%	63%	86%	55%
	Number of responses	11	18	23	16	14	33
Composite or modeled	United States Drought Monitor	64%	53%	65%	60%	64%	72%
	Number of responses	11	17	20	15	11	29

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Short-term drought is less than six months in duration. Long-term is six months or more in duration. BW (Arid – desert); BWh (Hot Desert Climate); BWk (Cold Desert Climate); BS (Semi-Arid); BSh (Hot Semi-Arid Climate); BSk (Cold Semi-Arid Climate).

Figure 9. Do Indicators Perform Equally in Geographical Areas of Dry Climates?

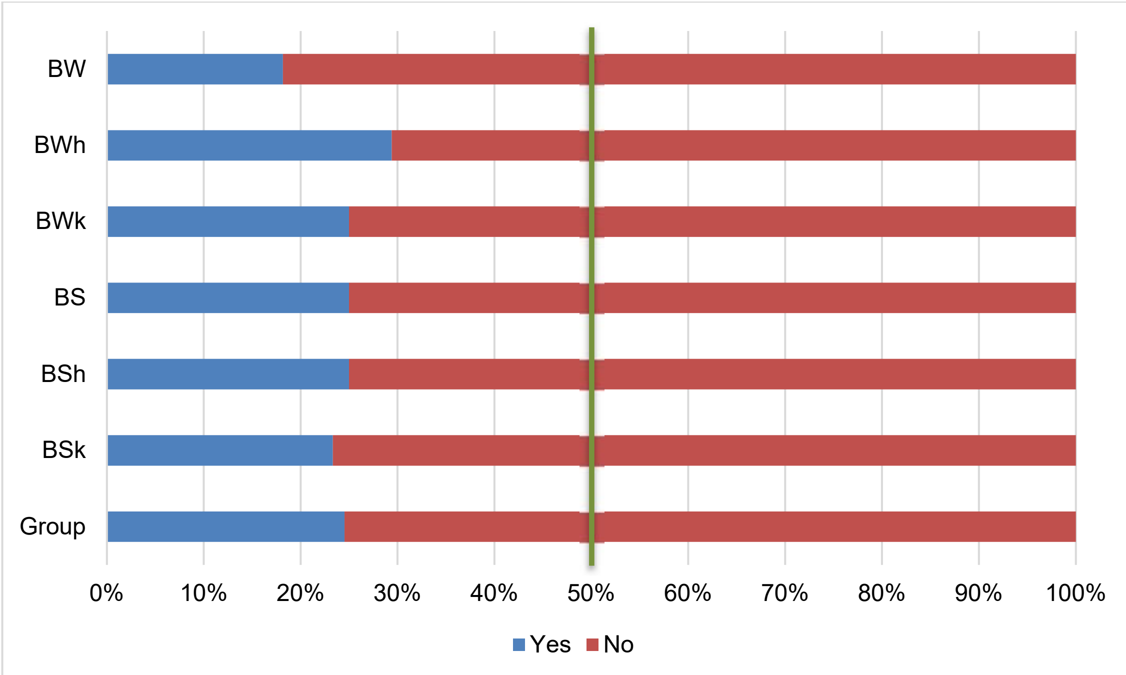


Figure 10. Do Indicators Perform Equally in Different Seasons in Dry Climates?

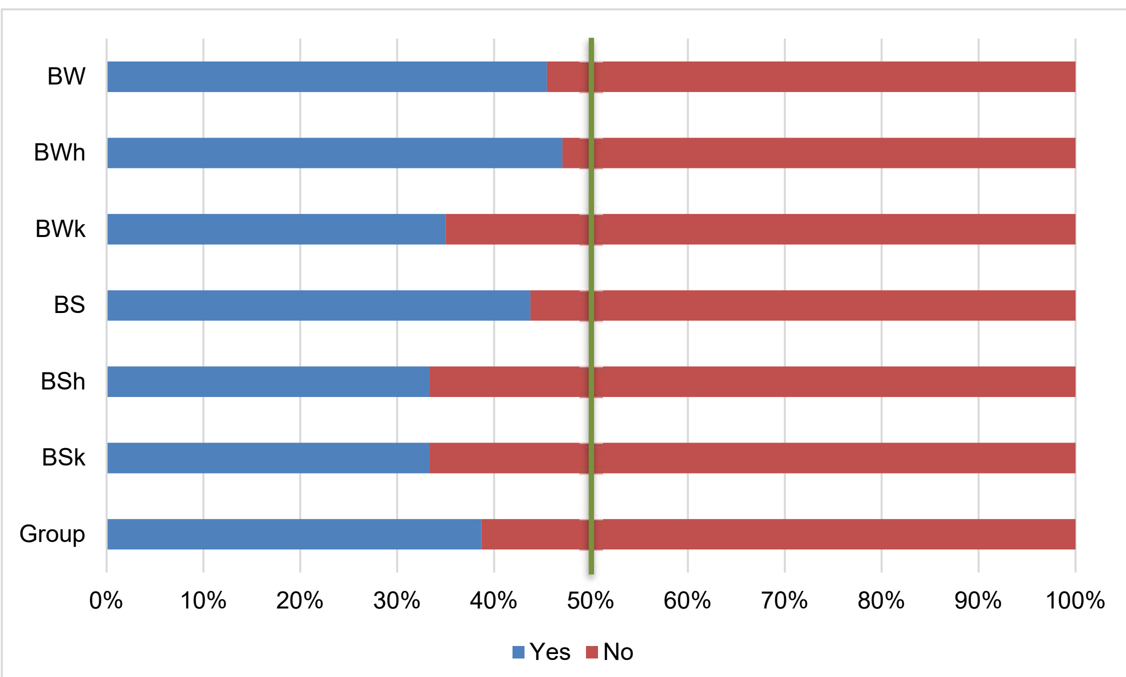


Table 20. Most Effective Indices and Indicators for Drought in Dry Climates *not* listed in the WMO *Handbook of Drought Indicators and Indices*

Indicator	Köppen Climate Zone					
	BW	BWh	BWk	BS	BSh	BSk
30-day Forecasts	-	-	-	50%	-	-
Crop Status	64%	59%	75%	63%	58%	77%
Groundwater Depth	64%	65%	50%	50%	58%	-
Precipitation Departures from Normal	-	-	60%	63%	-	70%
Precipitation Percentiles	73%	82%	65%	63%	67%	70%
Precipitation Ranks	55%	53%	55%	-	50%	50%
Reported Drought Impacts	73%	76%	70%	75%	67%	83%
Reservoir Storage	73%	88%	80%	81%	83%	77%
Soil Moisture	82%	88%	90%	75%	67%	90%
Streamflow	73%	76%	75%	75%	58%	70%
Temperature Departures from Normal	55%	59%	60%	63%	-	73%
Temperature Ranks	64%	65%	55%	50%	67%	57%
Vegetation Greenness	73%	71%	65%	56%	75%	60%
Water Use/Demand	64%	65%	55%	63%	50%	53%
Wildfire Locations/Reports	55%	59%	-	50%	50%	-
Number of responses	11	17	20	16	12	30

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. BW (Arid – desert); BWh (Hot Desert Climate); BWk (Cold Desert Climate); BS (Semi-Arid); BSh (Hot Semi-Arid Climate); BSk (Cold Semi-Arid Climate).

Köppen Climate Group C: Temperate Climates

Drought in North American temperate climates

Climate group C is characterized as having a temperature greater than 10°C in the warmest month, and less than 18°C but more than 0°C in the coldest month. There are 11 climate zones in the group, based on the seasonal precipitation type and temperature extremes, as follows (Heim, in litt.; Peel, Finlayson, & McMahon, 2007):

- Cs: Mediterranean
- Csa: Hot-Summer Mediterranean Climate
- Csb: Warm-Summer Mediterranean Climate
- Cw: Temperate with Dry Winters
- Cwa: Warm Oceanic Climate / Humid Subtropical Climate
- Cwb: Subtropical Highland Climate or Temperate Oceanic Climate with Dry Winters
- Cwc: Cold Subtropical Highland/Subpolar Oceanic
- Cf: Humid Subtropical
- Cfa: Hot-Summer Humid Subtropical Climate
- Cfb: Temperate Oceanic Climate
- Cfc: Subpolar Oceanic Climate

Köppen climate group C ranges through areas of central Mexico, the US West Coast and southern Plains to Southeast, and the west coast of Canada (Fig. 11). Of the 164 survey responses, 116 respondents reported their geographic area of responsibility included Köppen climate group C, with 51% (n=59) distributed between climate zones Csa, Csb and Cfa. Seven respondents were from Canada, 29 were from Mexico and 80 were from the United States (Table 21).

Almost all of the climate group C respondents indicated their area of responsibility experienced drought in the prior 10 years. None reported that drought had not occurred, but four respondents noted they did not know (Table 22).

More than half of the survey respondents from regions of temperate climates indicated drought occurred in more than five years out of the past 10. The same was true for each individual temperate climate zone with the exception of Csb, in which more respondents reported drought occurred in three to five years out of the past 10 (Table 23). This suggests that, in the past 10 years (at the time of writing), most areas with temperate climates in North America experienced drought in more years than they did not.

Drought duration ranged from one to more than 12 months long. No respondents reported drought that lasted less than one month in any of the group C climate zones. Overall, a small majority (54%) of respondents reported that typical drought lasted six months or longer (long-term). The duration of a typical drought varied considerably between the different climate zones. In climate zones Cw, Cwb, Cf and Cfa, the majority of respondents reported that typical drought lasted *less* than six months (short-term). In climate zones Cs, Csa, Csb, and Cfc, the majority of responses were that typical drought lasted *more* than six months (long-term). The prevalence of long-term drought was particularly evident for climate zone Csa, where 13 out of 18 respondents reported that typical drought lasted more than 12 months. In climate zones Cwa, Cwc, and Cfb, the responses were split evenly between a typical drought lasting less or more than six months (Table 24 and Fig. 12).

Factors affecting choice of indicators

The relevance of the indicator to the area or region was the most important factor when choosing indicators for temperate climates. Most respondents from each climate zone indicated this factor was very important. No other factor was considered very important for all climate zones. It is worth noting that 80% or more of the respondents indicated the availability of relevant and required data was very important for climate zones Cs, Cfb and Cfc. Similarly, 80% or more of the respondents reported the history of indicators used previously in the area or region was very important in zones Cfb and Cfc, and 80% of respondents felt the complexity or difficulty of the required calculation was very important for zone Cw (Table 25).

The most important factors when choosing indicators in temperate climates, listed in order of importance (from most to least), were as follows:

- Relevance of the indicator to the area or region
- Availability of relevant and required data to calculate the indicator
- The history of indicators used previously in the area or region
- Complexity or difficulty of the required calculation
- Familiarity with the specific indicator

Performance of indicators

Survey respondents reported that indicators do not perform equally well across their respective geographical areas of responsibility in eight temperate climate zones (Cs, Csa, Csb, Cw, Cwb, Cf, Cfa, Cfb), but do perform equally well in three (Cwa, Cwc and Cfc). However, in most cases the opinions were almost evenly split. The exceptions were for the humid subtropical climate zones Cf and Cfa, where a clear majority of respondents reported that indicators do not perform equally well across their respective geographical areas of responsibility (Table 26, Fig. 13).

The responses were similar, but not identical regarding the performance of indicators across different seasons. Survey respondents reported that indicators perform equally well across seasons only in temperate climate zone Cwa, although only by a margin of 3:2. Opinions were equally split for zone Csa. For all other climate zones, most respondents indicated that indicators *do not* perform equally well across seasons. For climate zones Cs, Csa, Cwa, Cwb, Cwc and Cfc, the opinions were evenly, or almost evenly split. However, a clear majority responded that indicators do not perform equally well in different seasons for climate zones Csb, Cw, Cf, Cfa and Cfb (Table 27, Fig. 14).

Drought indicators in North American temperate climates

Overall, 26 indicators were scored as very effective for monitoring short-term drought in temperate climates. Ten indicators were scored as very effective for long-term drought. The diversity of survey responses and the (relatively) large number of temperate climate zones resulted in a scattered set of results (Tables 28 and 29). However, many of the indicators were scored as very effective by only 50% of the respondents.

The USDM was the only indicator that was scored as very effective for short-term drought in all temperate climate zones (Table 28). Notably, the USDM was not scored as being very effective for long-term drought in climate zones Cs, Csa, Csb, and Cwa (Table 29).

Three other indicators were scored as very effective in most temperate climate zones for short-term drought: PNP, Standardized Precipitation Evapotranspiration Index (SPEI) and SPI. The results for these three indicators overlap such that, although none are very effective for every temperate climate zone, at least one of the three is very effective for each climate zone. Normalized Difference Vegetation Index was scored particularly highly for climate zones Cw and Cwb (Table 28).

No indicators were scored as very effective for long-term drought in all temperate climate zones, and no indicators were scored as very effective for zone Csb. SPI was scored as very effective for all but the Csb and Cfc climate zones. The USDM was the only indicator that was scored as very effective for the Cfc climate zone (Table 29). So, despite the USDM not being considered very effective for long-term drought in all climate zones, the SPI and USDM, used together, cover most but not all temperate climate zones for long-term drought.

Survey respondents scored 19 drought indicators that were not listed in the WMO Handbook as very effective for monitoring drought in temperate climates. Four were scored as very effective for all 11 temperate climate zones: Crop Status, Reservoir Storage, Soil Moisture and Streamflow. Of these, Reservoir Storage scored as very effective by an average of 79% of respondents, while Crop Status and Soil Moisture were scored as very effective by an average of 72% and 73% of respondents (respectively) (Table 30).

Figure 11. Distribution of Temperate Climates in North America

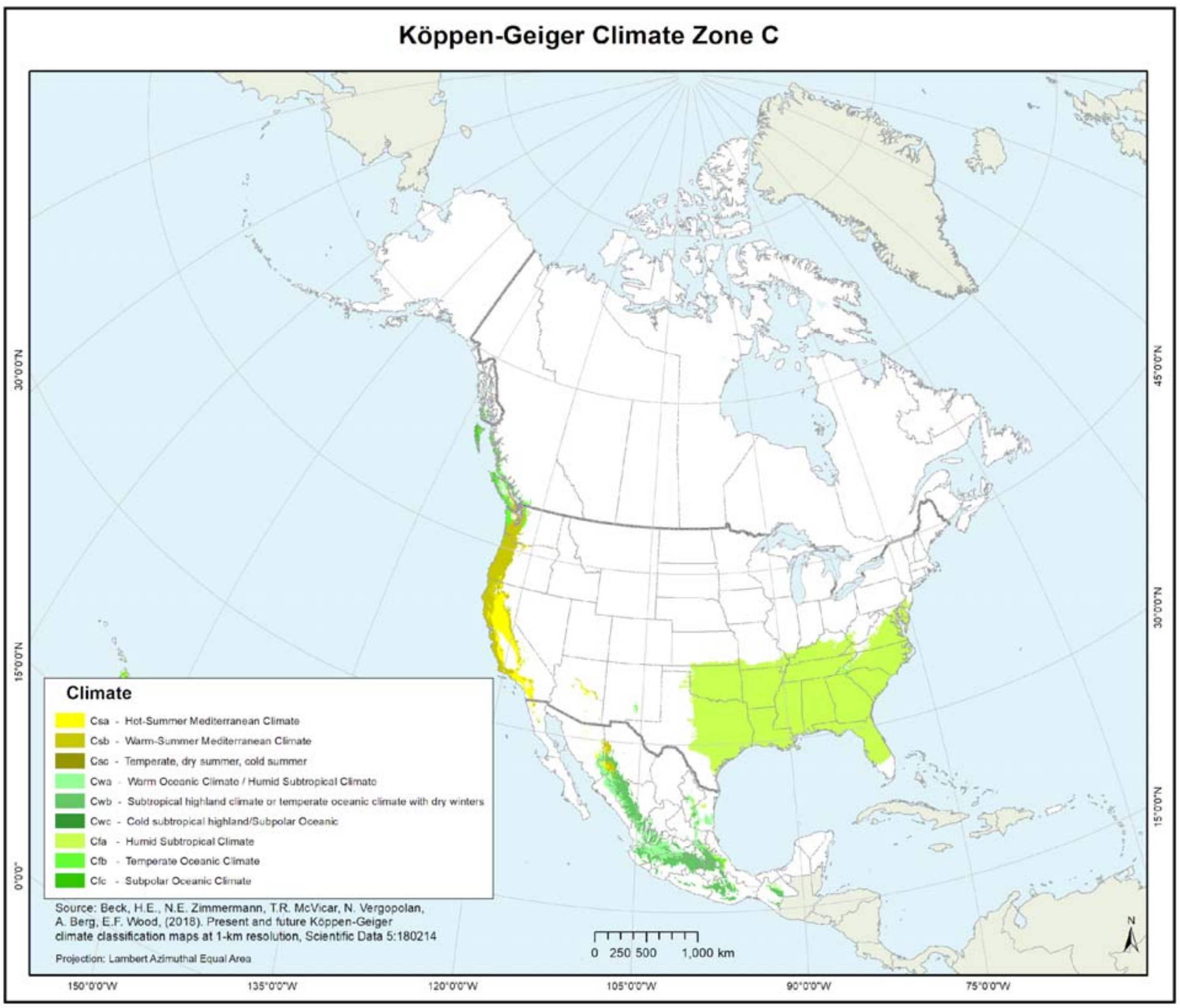


Table 21. Survey Respondents Active in Temperate Climates, by Country

Climate Zone	Canada	Mexico	United States	Total
Cs: Mediterranean	-	2	4	6
Csa: Hot-Summer Mediterranean Climate	-	2	17	19
Csb: Warm-Summer Mediterranean Climate	3	3	12	18
Cw: Temperate with Dry Winters	-	5	3	8
Cwa: Warm Oceanic Climate / Humid Subtropical Climate	-	1	5	6
Cwb: Subtropical highland climate or Temperate Oceanic Climate with Dry Winters	-	5	3	8
Cwc: Cold Subtropical Highland/Subpolar Oceanic	-	1	3	4
Cf: Humid Subtropical	-	5	6	11
Cfa: Hot-Summer Humid Subtropical Climate	1	4	17	22
Cfb: Temperate Oceanic Climate	2	1	5	8
Cfc: Subpolar Oceanic Climate	1	-	5	6
Total	7	29	80	116

Note: Data indicate the number of survey responses.

Table 22. Occurrence of Drought in Temperate Climates, in the Past 10 years

Climate Zone	Yes	No	Do not know
Cs: Mediterranean	6	-	-
Csa: Hot-Summer Mediterranean Climate	19	-	-
Csb: Warm-Summer Mediterranean Climate	17	-	1
Cw: Temperate with Dry Winters	7	-	1
Cwa: Warm Oceanic Climate / Humid Subtropical Climate	6	-	-
Cwb: Subtropical highland climate or Temperate Oceanic Climate with Dry Winters	7	-	1
Cwc: Cold subtropical highland/Subpolar Oceanic	4	-	-
Cf: Humid Subtropical	11	-	-
Cfa: Humid Subtropical Climate	21	-	1
Cfb: Temperate Oceanic Climate	8	-	-
Cfc: Subpolar Oceanic Climate	6	-	-
Total	112	-	4

Note: Data indicate the number of survey responses.

Table 23. Frequency of Drought in Temperate Climates

Climate Zone	Drought frequency (years)			
	1 – 2	3 – 5	5+	Do not know
Cs: Mediterranean	-	1	5	-
Csa: Hot-Summer Mediterranean Climate	1	6	11	1
Csb: Warm-Summer Mediterranean Climate	2	9	6	-
Cw: Temperate with Dry Winters	2	2	3	-
Cwa: Warm Oceanic Climate / Humid Subtropical Climate	1	1	4	-
Cwb: Subtropical highland climate or Temperate Oceanic Climate with Dry Winters	-	3	4	-
Cwc: Cold Subtropical Highland/Subpolar Oceanic	1	1	2	-
Cf: Humid Subtropical	2	3	6	-
Cfa: Hot-Summer Humid Subtropical Climate	5	5	10	1
Cfb: Temperate Oceanic Climate	1	2	5	-
Cfc: Subpolar Oceanic Climate	1	2	3	-
Total	16	35	59	2

Notes: Data indicate the number of survey responses. Drought frequency refers to how often drought was experienced in the past 10 years.

Table 24. Duration of Typical Drought in Temperate Climates

Climate Zone	Drought duration (months)				Short-term drought	Long-term drought
	1 – 3	3 – 6	6 – 12	12+		
Cs: Mediterranean	-	2	2	2	2	4
Csa: Hot-Summer Mediterranean Climate	-	3	2	13	3	15
Csb: Warm-Summer Mediterranean Climate	1	5	4	6	6	10
Cw: Temperate with Dry Winters	1	4	1	1	5	2
Cwa: Warm Oceanic Climate / Humid Subtropical Climate	1	2	1	2	3	3
Cwb: Subtropical highland climate or Temperate Oceanic Climate with Dry Winters	-	4	1	1	4	2
Cwc: Cold Subtropical Highland/Subpolar Oceanic	-	2	1	1	2	2
Cf: Humid Subtropical	2	4	3	1	6	4
Cfa: Hot-Summer Humid Subtropical Climate	4	9	5	2	13	7
Cfb: Temperate Oceanic Climate	1	3	3	1	4	4
Cfc: Subpolar Oceanic Climate	-	1	4	1	1	5
Total	10	39	27	31	49	58

Notes: Data indicate the number of survey responses, which differed for long-term drought and short-term drought. Short-term drought is less than six months in duration. Long-term is six months or more in duration.

Figure 12. Duration of Typical Drought in Temperate Climates: Short- vs. Long-term

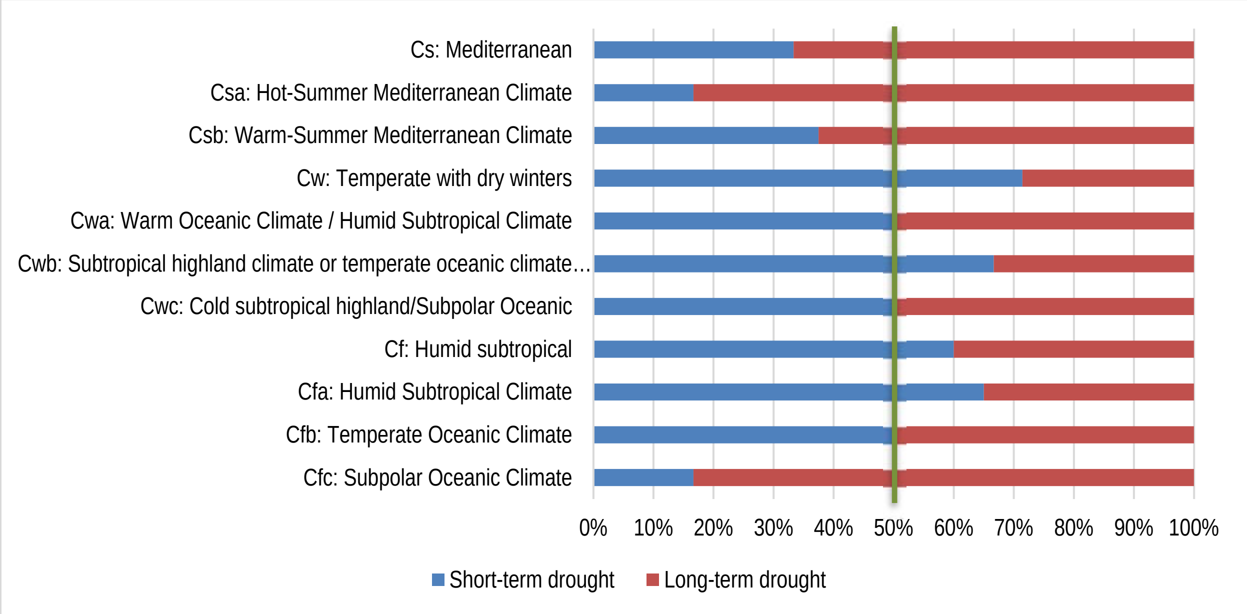


Table 25. Factors Affecting Choice of Indicators in Temperate Climates

Factors	Köppen Climate Zone										
	Cs	Csa	Csb	Cw	Cwa	Cwb	Cwc	Cf	Cfa	Cfb	Cfc
Availability of required data to calculate the indicator	80%	75%	69%	60%	60%	57%	-	50%	50%	86%	80%
Complexity or difficulty of the required calculation	60%	-	-	80%	-	57%	-	50%	-	57%	-
Relevance of the indicator to the area/region	80%	81%	69%	60%	80%	57%	67%	75%	72%	86%	80%
Familiarity with the specific indicator	60%	69%	-	-	-	-	-	50%	61%	57%	-
History of indicators used previously in the area or region	60%	56%	-	-	-	-	-	50%	50%	86%	80%
Number of responses	5	16	13	5	5	7	3	8	18	7	5

Notes: Data indicate where at least 50% of the survey respondents scored the factor as very important for the respective climate zone. Cs (Mediterranean); Csa (Hot Summer Mediterranean Climate); Csb (Warm Summer Mediterranean Climate); Cw (Temperate with dry winters); Cwa (Warm Oceanic Climate / Humid Subtropical Climate); Cwb (Subtropical highland climate or temperate oceanic climate with dry winters); Cwc (Cold subtropical highland / Subpolar Oceanic); Cf (Humid subtropical); Cfa (Hot-Summer Humid Subtropical Climate); Cfb (Temperate Oceanic Climate); Cfc (Subpolar Oceanic Climate).

Table 26. Performance of Indicators Across Geographical Area in Temperate Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
Cs - Mediterranean	2	3
Csa - Hot-Summer Mediterranean Climate	7	9
Csb - Warm-Summer Mediterranean Climate	6	7
Cw - Temperate with Dry Winters	2	3
Cwa - Warm Oceanic Climate / Humid Subtropical Climate	3	2
Cwb - Subtropical highland climate or Temperate Oceanic Climate with Dry Winters	2	5
Cwc - Cold Subtropical Highland/Subpolar Oceanic	2	1
Cf - Humid Subtropical	2	6
Cfa - Humid Subtropical Climate	5	13
Cfb - Temperate Oceanic Climate	3	4
Cfc - Subpolar Oceanic Climate	3	2
Total	37	55

Note: Data indicate the number of survey responses.

Table 27. Performance of Indicators Across Different Seasons in Temperate Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
Cs - Mediterranean	2	3
Csa - Hot-Summer Mediterranean Climate	8	8
Csb - Warm-Summer Mediterranean Climate	5	8
Cw - Temperate with Dry Winters	1	4
Cwa - Warm Oceanic Climate / Humid Subtropical Climate	3	2
Cwb - Subtropical Highland Climate or Temperate Oceanic Climate with Dry Winters	3	4
Cwc - Cold Subtropical Highland/Subpolar Oceanic	1	2
Cf - Humid Subtropical	3	5
Cfa - Humid Subtropical Climate	5	13
Cfb - Temperate Oceanic Climate	2	5
Cfc - Subpolar Oceanic Climate	2	3
Total	35	57

Note: Data indicate the number of survey responses.

Figure 13. Do Indicators Perform Equally in Geographical Areas of Temperate Climates?

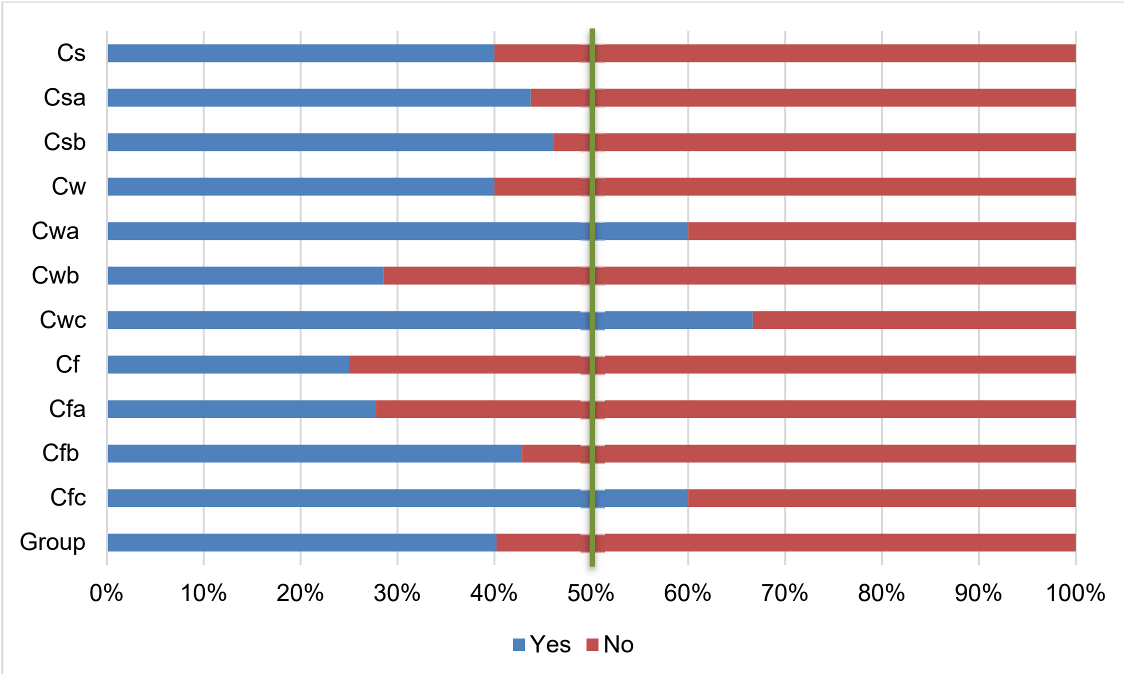


Figure 14. Do Indicators Perform Equally in Different Seasons in Temperate Climates?

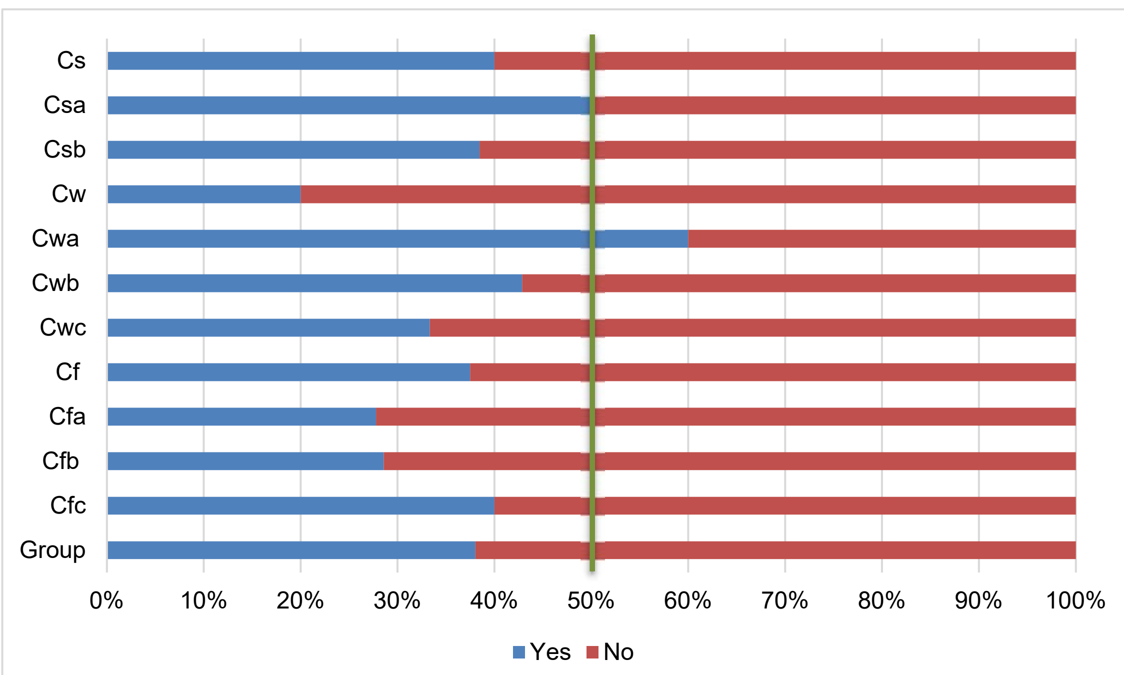


Table 28. Most Effective Indices and Indicators for Short-term Drought in Temperate Climates

Category	Indicator	Köppen Climate Zone										
		Cs	Csa	Csb	Cw	Cwa	Cwb	Cwc	Cf	Cfa	Cfb	Cfc
Meteorology	Crop Moisture Index	67%	-	-	50%	50%	63%	75%	50%	45%	-	-
	Crop-specific Drought Index	-	-	-	50%	-	50%	-	-	-	-	-
	Drought Area Index	-	-	-	-	-	-	50%	-	-	-	-
	Drought Reconnaissance Index	-	-	-	-	-	-	50%	-	-	-	-
	Keetch–Byram Drought Index	-	-	-	50%	-	-	-	-	-	-	-
	Palmer Drought Severity Index	50%	-	-	50%	-	63%	50%	60%	-	-	-
	Percent of Normal Precipitation	83%	67%	56%	-	50%	50%	50%	50%	70%	-	50%
	Standardized Precipitation Evapotranspiration Index	50%	-	-	67%	67%	63%	75%	60%	50%	50%	50%
	Standardized Precipitation Index	67%	56%	-	67%	50%	63%	50%	80%	70%	75%	50%
	Other (unspecified)	-	-	-	-	-	-	50%	-	-	-	50%
	Number of responses	6	18	16	6	6	8	4	10	20	8	6
Soil moisture	Soil Moisture Anomaly	-	-	-	67%	-	50%	-	50%	-	-	-
	Evapotranspiration Deficit Index	-	-	-	50%	-	-	-	-	-	-	-
	Soil Moisture Deficit Index	50%	-	-	67%	-	63%	50%	50%	-	-	-
	Soil Water Storage	-	-	-	50%	-	50%	-	50%	-	-	-
	Number of responses	6	17	15	6	6	8	4	10	19	8	6
Hydrology	Palmer Hydrological Drought Index	-	-	-	-	-	-	67%	-	-	-	-
	Number of responses	5	16	13	5	5	7	3	9	18	7	5
Remote sensing	Enhanced Vegetation Index	50%	-	-	50%	-	50%	-	-	-	-	-
	Evaporative Stress Index	50%	-	-	50%	50%	50%	50%	60%	-	-	-
	Normalized Difference Vegetation Index	67%	-	-	83%	67%	88%	75%	70%	-	50%	-
	Normalized Difference Water Index & Land Surface Water Index	50%	-	-	50%	50%	-	50%	-	-	-	-
	Vegetation Condition Index	-	-	-	50%	-	50%	50%	-	-	-	-
	Vegetation Drought Response Index	50%	-	-	67%	67%	50%	75%	50%	-	-	-
	Vegetation Health Index	-	-	-	50%	-	50%			-	-	-
	Water Requirement Satisfaction Index	50%	-	-	50%	-	50%	50%	50%	-	-	-
	Number of responses	6	17	14	6	6	8	4	10	19	8	6
Composite or modeled	Global Land Data Assimilation System	-	-	-	50%	-	50%	-	-	-	-	-
	Multivariate Standardized Drought Index	-	-	-	50%	-	63%	-	-	-	-	-
	United States Drought Monitor	67%	59%	57%	67%	67%	71%	75%	78%	74%	50%	67%
	Number of responses	6	17	14	6	6	8	4	9	19	8	6

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Short-term drought is less than six months in duration. Cs (Mediterranean); Csa (Hot Summer Mediterranean Climate); Csb (Warm Summer Mediterranean Climate); Cw (Temperate with dry winters); Cwa (Warm Oceanic Climate / Humid Subtropical Climate); Cwb (Subtropical highland climate or temperate oceanic climate with dry winters); Cwc (Cold subtropical highland/Subpolar Oceanic); Cf (Humid subtropical); Cfa (Hot-Summer Humid Subtropical Climate); Cfb (Temperate Oceanic Climate); Cfc (Subpolar Oceanic Climate).

Table 29. Most Effective Indices and Indicators for Long-term Drought in Temperate Climates

Category	Indicator	Köppen Climate Zone										
		Cs	Csa	Csb	Cw	Cwa	Cwb	Cwc	Cf	Cfa	Cfb	Cfc
Meteorology	Palmer Drought Severity Index	-	-	-	-	-	57%	-	56%	61%	-	-
	Percent of Normal Precipitation	-	53%	-	-	-	-	-	56%	72%	57%	-
	Rainfall Anomaly Index	-			60%							-
	Standardized Precipitation Evapotranspiration Index	-	-	-	60%	-	57%	-	56%	-	-	-
	Standardized Precipitation Index	60%	53%	-	80%	60%	71%	67%	89%	72%	71%	-
	Number of responses	5	17	15	5	5	7	3	9	18	7	5
Hydrology	Palmer Hydrological Drought Index	-	-	-	-	-	-	67%	-	-	-	-
	Standardized Reservoir Supply Index	-	-	-	60%	-	-	-	-	-	-	-
	Number of responses	5	16	13	5	5	7	3	9	18	7	5
Composite or modeled	Global Land Data Assimilation System	-	-	-	60%	-	57%	-	50%	-	-	-
	Multivariate Standardized Drought Index	-	-	-	60%	-	57%	-	50%	-	-	-
	United States Drought Monitor	-	-	-	60%	-	57%	67%	75%	78%	57%	60%
	Number of responses	5	16	13	5	5	7	3	8	18	7	5

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Long-term is six months or more in duration. Cs (Mediterranean); Csa (Hot Summer Mediterranean Climate); Csb (Warm Summer Mediterranean Climate); Cw (Temperate with Dry Winters); Cwa (Warm Oceanic Climate / Humid Subtropical Climate); Cwb (Subtropical Highland Climate or Temperate Oceanic Climate with Dry Winters); Cwc (Cold Subtropical Highland/Subpolar Oceanic); Cf (Humid Subtropical); Cfa (Hot-Summer Humid Subtropical Climate); Cfb (Temperate Oceanic Climate); Cfc (Subpolar Oceanic Climate).

Table 30. Most Effective Indices and Indicators for Drought in Temperate Climates *not* listed in the WMO *Handbook of Drought Indicators and Indices*

Indicator	Köppen Climate Zone										
	Cs	Csa	Csb	Cw	Cwa	Cwb	Cwc	Cf	Cfa	Cfb	Cfc
5-day Forecasts	80%	50%	-	60%	-	71%	-	63%	56%	57%	-
8 to 14-day Forecasts	-	-	-	-	-	-	-	-	-	57%	-
30-day Forecasts	-	-	-	60%	-	-	-	50%	-	57%	-
Crop Status	100%	63%	54%	80%	60%	71%	67%	88%	78%	71%	60%
Groundwater Depth	80%	50%	-	60%	-	57%	-	63%	56%	57%	-
Local Burn Bans	-	-	-	60%	-	-	-	-	-	-	-
Precipitation Departures from Normal	80%	69%	62%	-	-	57%	-	-	72%	57%	60%
Precipitation Percentiles	-	63%	54%	-	-	57%		63%	61%	71%	-
Precipitation Ranks	-	-	-	-	-	-	-	50%	-	-	-
Reported Drought Impacts	60%	75%	54%	-	60%	-	-	63%	72%	86%	80%
Reservoir Storage	100%	81%	85%	80%	80%	71%	67%	75%	67%	86%	80%
Soil Moisture	60%	56%	77%	80%	60%	71%	67%	88%	83%	86%	80%
Streamflow	80%	63%	69%	60%	60%	57%	67%	75%	78%	71%	80%
Temperature Departures from Normal	80%	50%	46%	60%	-	57%	-	50%	50%	71%	60%
Temperature Ranks	60%	-	-	-	-	-	-	63%	-	71%	60%
Vegetation Greenness	80%	56%	54%	80%	80%	71%	67%	63%	61%	-	-
Water Quality	-	-	-	-	-	-	-	-	-	-	60%
Water Use (Demand)	80%	50%	54%	60%	-	57%	-	-	-	71%	60%
Wildfire Locations /Reports	60%	50%	-	60%	-	57%	-	-	-	-	-
Number of responses	5	16	13	5	5	7	3	8	18	7	5

Notes: Data indicate the percentage of survey responses that scored each indicator as very effective for the respective climate zone. Cs (Mediterranean); Csa (Hot Summer Mediterranean Climate); Csb (Warm Summer Mediterranean Climate); Cw (Temperate with Dry Winters); Cwa (Warm Oceanic Climate / Humid Subtropical Climate); Cwb (Subtropical Highland Climate or Temperate Oceanic Climate with Dry Winters); Cwc (Cold Subtropical Highland/Subpolar Oceanic); Cf (Humid Subtropical); Cfa (Hot-Summer Humid Subtropical Climate); Cfb (Temperate Oceanic Climate); Cfc (Subpolar Oceanic Climate).

Köppen Climate Group D: Continental Climates

Drought in North American continental climates

Climate group D is characterized by having a temperature of greater than 10°C in the warmest month, and 0°C or less in the coldest month. There are 12 climate zones in the group, based on seasonal precipitation type and temperature extremes, as follows (Heim, in litt.; Peel, Finlayson, & McMahon, 2007):

- Dsa: Humid Continental Climate–Dry Warm Summer
- Dsb: Humid Continental Climate–Dry Cool Summer
- Dsc: Continental Subarctic–Cold Dry Summer
- Dsd: Continental Subarctic–Dry Summer, Very Cold Winter
- Dwa: Humid Continental Hot Summers with Dry Winters
- Dwb: Humid Continental Mild Summer with Dry Winters
- Dwc: Subarctic with Cool Summers and Dry Winters
- Dwd: Subarctic with Cold Winters and Dry Winters
- Dfa: Humid Continental Hot Summers with Year-round Precipitation
- Dfb: Humid Continental Mild Summer, Wet All Year
- Dfc: Subarctic with Cool Summers and Year-round Precipitation
- Dfd: Subarctic with Cold Winters and Year-round Precipitation

Köppen climate group D covers much of the midwestern, northeastern and northwestern parts of the contiguous United States, most of Alaska plus areas of higher elevation. Most of Canada south of the Arctic Circle is also within climate group D (Fig. 15).

Of the 164 survey responses, 138 respondents reported their geographic area of responsibility included Köppen climate group D. Respondents' areas of responsibility were distributed amongst all of the climate zones, with a large majority (73%) responsible in five climate zones: Dsa, Dsb, Dfa, Dfb, and Dfc. Eight or fewer respondents reported their area of responsibility included each of the other seven climate zones. Forty-six respondents were from Canada, five were from Mexico and 87 were from the United States (Table 31).

All the climate group D respondents indicated their area of responsibility experienced drought in the prior 10 years except for a single response for climate zone Dfb (Table 32). The frequency of drought in continental climate zones ranged from one to more than five years out of the past 10 years. Four respondents reported they did not know how often their areas of responsibility had experienced drought (Table 33). There was no clear consensus amongst respondents regarding the frequency of drought in the different climate zones or within climate group D. This may reflect the extensive geographic distribution of this climate group across North America.

Drought duration ranged from one to more than 12 months long. No respondents reported drought that lasted less than one month in any of the group D climate zones. Overall, most respondents (57%) reported that typical drought lasted less than six months (short-term). However, the duration of a typical drought varied considerably between the different climate zones. In climate zones Dsb, Dwa, Dwb, Dwd and Dfc, a small majority of respondents reported that typical drought lasted six months or more (long-term). In climate zones Dsa, Dsc, Dsd, Dwc, Dfa and Dfb, most respondents indicated that typical drought lasted six months or less (short-term). For climate zones Dfa and Dfb, short-term drought was indicated by a large majority of respondents (Table 34 and Fig. 16).

Factors affecting choice of indicators

No single factor was scored as very important for choosing indicators for every continental climate zone. The availability of relevant and required data was considered very important for each climate zone except Dsc. A total of 80% of respondents indicated data availability was very important for zone Dwc and 92% indicated data availability was very important for zone Dsa. It is worth noting that climate zone Dsc was only represented by three survey respondents. But two out of these three authorities did not feel data availability was a very important factor (Table 35).

Regarding the remaining factors, 92% of the respondents indicated the relevance of the indicator was very important for climate zone Dsa, as did more than 80% of respondents for zones Dwa, Dwb and Dfb. More than 80% of respondents indicated the history of indicators used previously in the area or region was very important for zones Dwa and Dwb. Complexity or difficulty of the required calculation was not reported as a very important factor for any climate zone (Table 35).

The most important factors when choosing indicators in continental climates, listed in order of importance (from most to least), were as follows:

- Availability of relevant and required data to calculate the indicator
- Relevance of the indicator to the area or region
- The history of indicators used previously in the area or region
- Familiarity with the specific indicator
- Complexity or difficulty of the required calculation

Performance of indicators

Survey respondents did not report that indicators perform equally well across their respective geographical areas of responsibility for any continental climate zone. Most reported indicators do not perform equally well, although responses were split for climate zones Dwd and Dfd (Table 36, Fig. 17).

There was less agreement regarding performance across seasons for continental climate zones. Survey respondents reported that indicators do not perform equally well for seven climate zones (Dsa, Dsb, Dwa, Dwb, Dfa, Dfb and Dfc) but do perform equally well for four zones (Dsc, Dwc, Dwd and Dfd). Opinions were equally split for zone Dsd. It is notable that of the six subarctic climate zones, indicators were reported not to perform equally in only one (Dfc), although opinions were evenly, or almost evenly split for the other five (Table 37, Fig. 18).

Drought indicators in North American continental climates

Overall, 11 indicators were scored as very effective for monitoring short-term drought in continental climates. Fifteen indicators were scored as very effective for long-term drought (Table 38). However, 9 of the indicators scored for long-term drought were scored as such for only a single climate zone and were not scored highly for any other climate zones. Those same indicators were scored as very effective by exactly half of the respondents; therefore, they were scored as not very effective in those same climate zones by the other half of the respondents.

No indicators were scored as very effective for short-term drought in every continental climate zone. The closest was the USDM, which was scored as very effective in each climate zone except for Dsa and Dfd. The USDM was the only indicator scored as very effective in the Dwc climate zone. Three other indicators—PNP, SPEI and SPI—scored well in seven or eight climate zones. SPI was notable for being scored as very effective by 88% and 86% of the respondents for climate zones Dwa and Dwb (respectively) (Table 38).

None of the indicators listed in the WMO *Handbook of Drought Indicators and Indices* were scored as very effective for monitoring long-term drought in climate zone Dfd. The USDM was scored as very effective for long-term drought in all continental climate zones except Dfd. Three other indicators were scored as very effective for long-term drought in *most* continental climate zones: SPEI, PNP and SPI. The results for these indicators overlap such that, although none are very effective for every continental climate zone, at least one is very effective for each climate zone except Dfd (Table 38).

Survey respondents scored 19 drought indicators that were not listed in the WMO Handbook as very effective for monitoring drought in continental climates. Three indicators—Crop Status, Precipitation Percentiles and Soil Moisture—were scored as very effective for all climate zones, including Dfd. Soil Moisture was scored as very effective by an average of 82% of respondents (Table 39).

Figure 15. Distribution of Continental Climates in North America

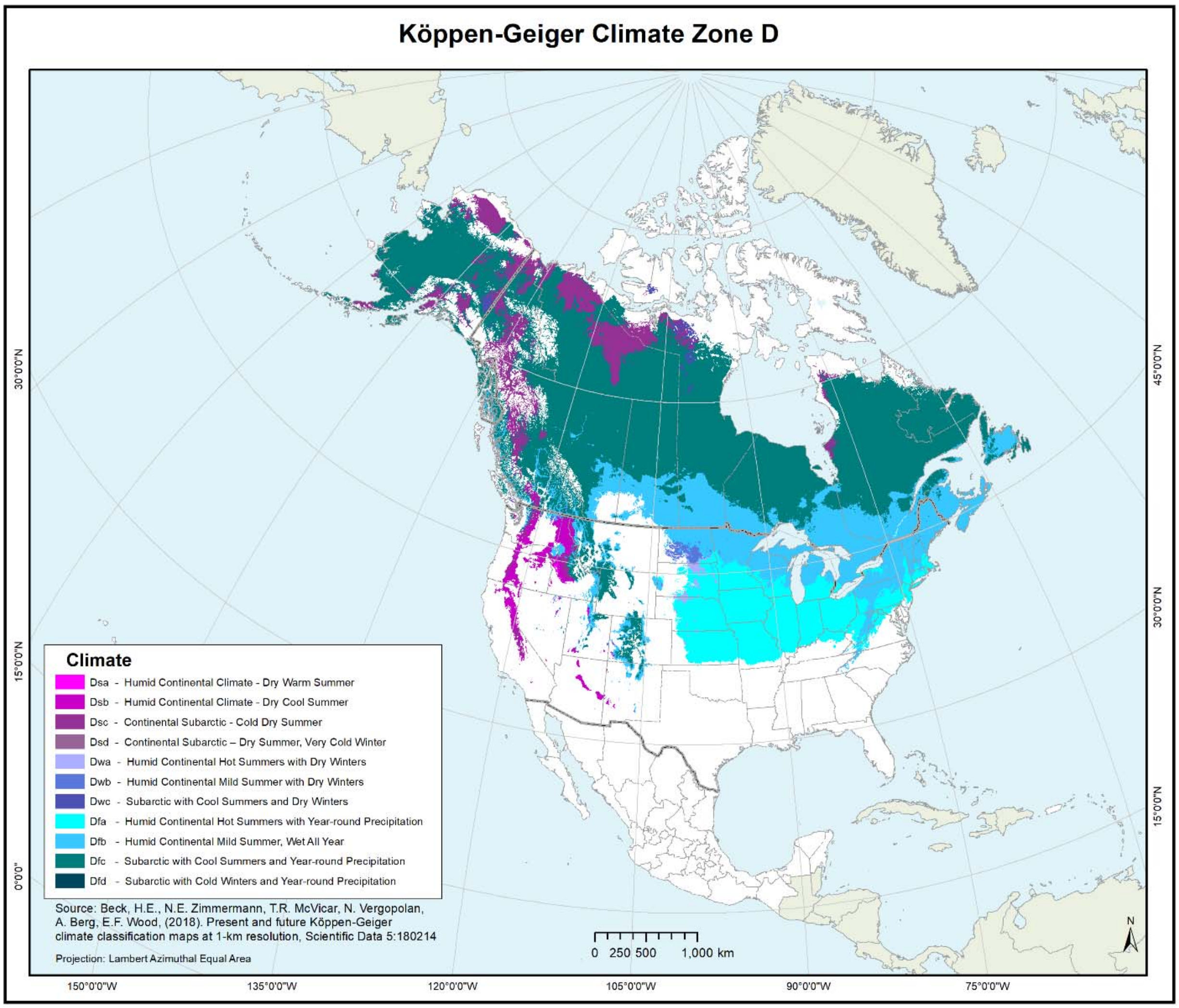


Table 31. Survey Respondents Active in Continental Climates, by Country

Climate Zone	Canada	Mexico	United States	Total
Dsa: Humid Continental Climate—Dry Warm Summer	5	1	10	16
Dsb: Humid Continental Climate—Dry Cool Summer	3	-	12	15
Dsc: Continental Subarctic—Cold Dry Summer	2	-	2	4
Dsd: Continental Subarctic—Dry Summer, Very Cold Winter	2	-	2	4
Dwa: Humid Continental Hot Summers with Dry Winters	1	1	6	8
Dwb - Humid Continental Mild Summer with Dry Winters	-	1	6	7
Dwc: Subarctic with Cool Summers and Dry Winters	3	-	2	5
Dwd: Subarctic with Cold Winters and Dry Winters	2	-	3	5
Dfa: Humid Continental Hot Summers with Year-round Precipitation	8	1	17	26
Dfb: Humid Continental Mild Summer, Wet All Year	11	1	17	29
Dfc: Subarctic with Cool Summers and Year-round Precipitation	6	-	9	15
Dfd: Subarctic with Cold Winters and Year-round Precipitation	3	-	1	4
Total	46	5	87	138

Note: Data indicate the number of survey responses.

Table 32. Occurrence of Drought in Continental Climates, in the Past 10 years

Climate Zone	Yes	No	Do not know
Dsa: Humid Continental Climate—Dry Warm Summer	16	-	-
Dsb: Humid Continental Climate—Dry Cool Summer	15	-	-
Dsc: Continental Subarctic—Cold Dry Summer	4	-	-
Dsd: Continental Subarctic—Dry Summer, Very Cold Winter	4	-	-
Dwa: Humid Continental Hot Summers with Dry Winters	8	-	-
Dwb - Humid Continental Mild Summer with Dry Winters	7	-	-
Dwc: Subarctic with Cool Summers and Dry Winters	5	-	-
Dwd: Subarctic with Cold Winters and Dry Winters	5	-	-
Dfa: Humid Continental Hot Summers with Year-round Precipitation	26	-	-
Dfb: Humid Continental Mild Summer, Wet All Year	28	1	-
Dfc: Subarctic with Cool Summers and Year-round Precipitation	15	-	-
Dfd: Subarctic with Cold Winters and Year-round Precipitation	4	-	-
Total	137	1	-

Note: Data indicate the number of survey responses.

Table 33. Frequency of Drought in Continental Climates

Climate Zone	Drought frequency (years)			
	1 – 2	3 – 5	5+	Do not know
Dsa: Humid Continental Climate—Dry Warm Summer	2	4	9	1
Dsb: Humid Continental Climate—Dry Cool Summer	2	7	6	-
Dsc: Continental Subarctic—Cold Dry Summer	2	2	-	-
Dsd: Continental Subarctic—Dry Summer, Very Cold Winter	1	2	1	-
Dwa: Humid Continental Hot Summers with Dry Winters	1	1	5	1
Dwb - Humid Continental Mild Summer with Dry Winters	1	1	5	-
Dwc: Subarctic with Cool Summers and Dry Winters	1	3	1	-
Dwd: Subarctic with Cold Winters and Dry Winters	1	2	2	-
Dfa: Humid Continental Hot Summers with Year-round Precipitation	9	6	10	1
Dfb: Humid Continental Mild Summer, Wet All Year	10	9	8	1
Dfc: Subarctic with Cool Summers and Year-round Precipitation	3	6	6	-
Dfd: Subarctic with Cold Winters and Year-round Precipitation	1	3	-	-
Total	34	46	53	4

Notes: Data indicate the number of survey responses. Drought frequency refers to how often drought was experienced in the past 10 years.

Table 34. Duration of Typical Drought in Continental Climates

Climate Zone	Drought duration (months)				Short-term drought	Long-term drought
	1 – 3	3 – 6	6 – 12	12+		
Dsa: Humid Continental Climate—Dry Warm Summer	3	6	2	4	9	6
Dsb: Humid Continental Climate—Dry Cool Summer	2	4	4	4	6	8
Dsc: Continental Subarctic—Cold Dry Summer	1	3	-	-	4	-
Dsd: Continental Subarctic—Dry Summer, Very Cold Winter	-	3	-	1	3	1
Dwa: Humid Continental Hot Summers with Dry Winters	1	2	3	2	3	5
Dwb - Humid Continental Mild Summer with Dry Winters	-	2	3	2	2	5
Dwc: Subarctic with Cool Summers and Dry Winters	-	3	1	1	3	2
Dwd: Subarctic with Cold Winters and Dry Winters	-	2	2	1	2	3
Dfa: Humid Continental Hot Summers with Year-round Precipitation	7	11	5	2	18	7
Dfb: Humid Continental Mild Summer, Wet All Year	7	12	4	5	19	9
Dfc: Subarctic with Cool Summers and Year-round Precipitation	2	4	4	5	6	9
Dfd: Subarctic with Cold Winters and Year-round Precipitation	-	2	1	1	2	2
Total	23	54	29	28	77	57

Notes: Data indicate the number of survey responses, which differed for long-term drought and short-term drought. Short-term drought is less than six months in duration. Long-term is six months or more in duration.

Table 35. Factors Affecting Choice of Indicators in Continental Climates

Factors	Köppen Climate Zone											
	Dsa	Dsb	Dsc	Dsd	Dwa	Dwb	Dwc	Dwd	Dfa	Dfb	Dfc	Dfd
Availability of required data to calculate the indicator	92%	78%	-	75%	57%	50%	80%	75%	55%	61%	50%	50%
Complexity or difficulty of the required calculation	-	-	-	-	-	-	-	-	-	-	-	-
Relevance of the indicator to the area/region	92%	67%	-	50%	86%	83%	60%	50%	70%	83%	64%	-
Familiarity with the specific indicator	58%	-	67%	-	71%	67%	-	50%	75%	65%	50%	50%
History of indicators used previously in the area/region	75%	-	-	-	86%	83%	-	50%	60%	65%	64%	-
Number of responses	12	9	3	4	7	6	5	4	20	23	14	4

Notes: Data indicate where at least 50% of the survey respondents scored the factor as very important for the respective climate zone. Dsa (Humid Continental Climate-Dry Warm Summer); Dsb (Humid Continental Climate–Dry Cool Summer); Dsc (Continental Subarctic–Cold Dry Summer); Dsd (Continental Subarctic–Dry Summer with Very Cold Winter); Dwa (Humid Continental–Hot Summers with Dry Winters); Dwb (Humid Continental-Mild Summer with Dry Winters); Dwc (Subarctic with Cool Summers and Dry Winters); Dwd (Subarctic with Cold Winters and Dry Winters); Dfa (Humid Continental Hot Summers with Year-round Precipitation); Dfb (Humid Continental Mild Summer, Wet All Year); Dfc (Subarctic with Cool Summers and Year-round Precipitation); Dfd (Subarctic with Cold Winters and Year-round Precipitation).

Figure 16. Duration of Typical Drought in Continental Climates: Short- vs. Long-term

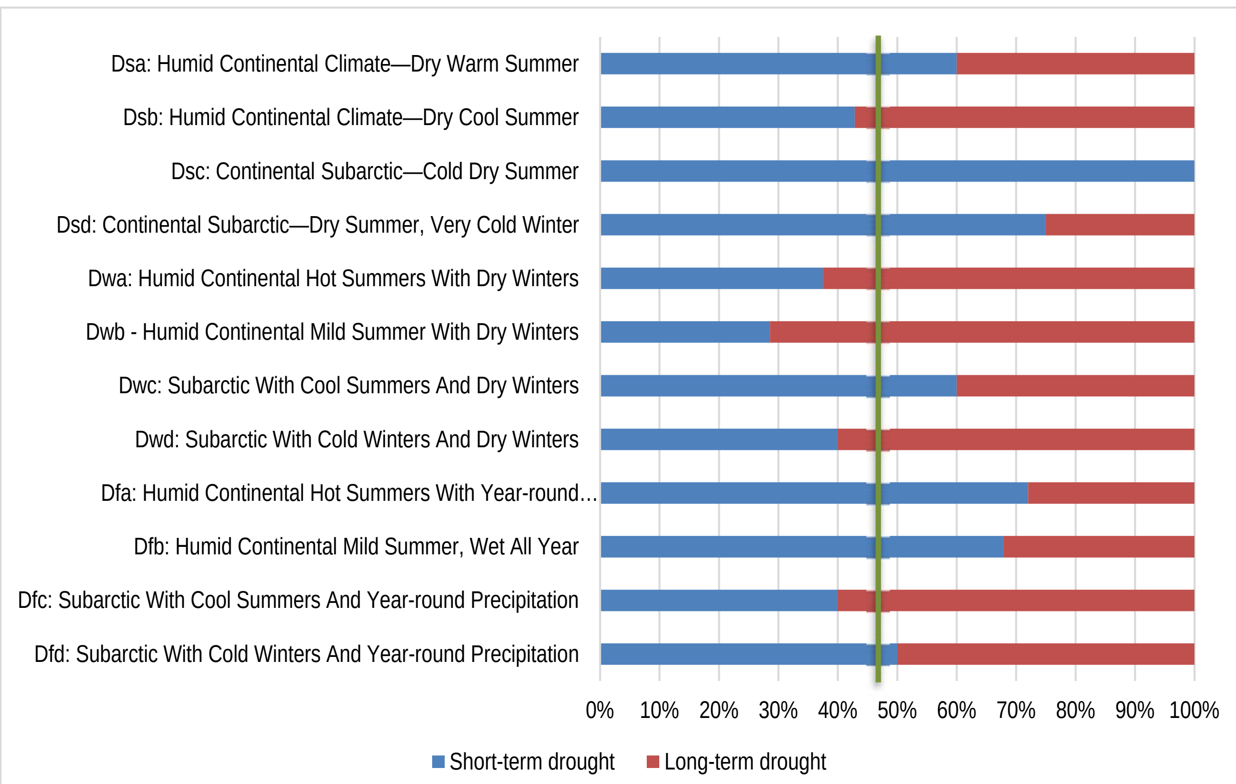


Table 36. Performance of Indicators Across Geographical Area in Continental Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
Dsa - Humid Continental Climate - Dry Warm Summer	3	9
Dsb - Humid Continental Climate - Dry Cool Summer	3	6
Dsc - Continental Subarctic - Cold Dry Summer	1	2
Dsd - Continental Subarctic - Dry Summer, Very Cold Winter	1	3
Dwa - Humid Continental Hot Summers with Dry Winters	2	5
Dwb - Humid Continental Mild Summer with Dry Winters	1	5
Dwc - Subarctic with Cool Summers and Dry Winters	2	3
Dwd - Subarctic with Cold Winters and Dry Winters	2	2
Dfa - Humid Continental Hot Summers with Year-round Precipitation	9	11
Dfb - Humid Continental Mild Summer, Wet All Year	7	17
Dfc - Subarctic with Cool Summers and Year-round Precipitation	5	10
Dfd - Subarctic with Cold Winters and Year-round Precipitation	2	2
Total	38	75

Note: Data indicate the number of survey responses.

Table 37. Performance of Indicators Across Different Seasons in Continental Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
Dsa - Humid Continental Climate - Dry Warm Summer	3	9
Dsb - Humid Continental Climate - Dry Cool Summer	3	6
Dsc - Continental Subarctic - Cold Dry Summer	2	1
Dsd - Continental Subarctic - Dry Summer, Very Cold Winter	2	2
Dwa - Humid Continental Hot Summers with Dry Winters	2	5
Dwb - Humid Continental Mild Summer with Dry Winters	1	5
Dwc - Subarctic with Cool Summers and Dry Winters	3	2
Dwd - Subarctic with Cold Winters and Dry Winters	3	1
Dfa - Humid Continental Hot Summers with Year-round Precipitation	5	15
Dfb - Humid Continental Mild Summer, Wet All Year	5	19
Dfc - Subarctic with Cool Summers and Year-round Precipitation	5	10
Dfd - Subarctic with Cold Winters and Year-round Precipitation	3	1
Total	37	76

Note: Data indicate the number of survey responses.

Figure 17. Do Indicators Perform Equally in Geographical Areas of Continental Climates?

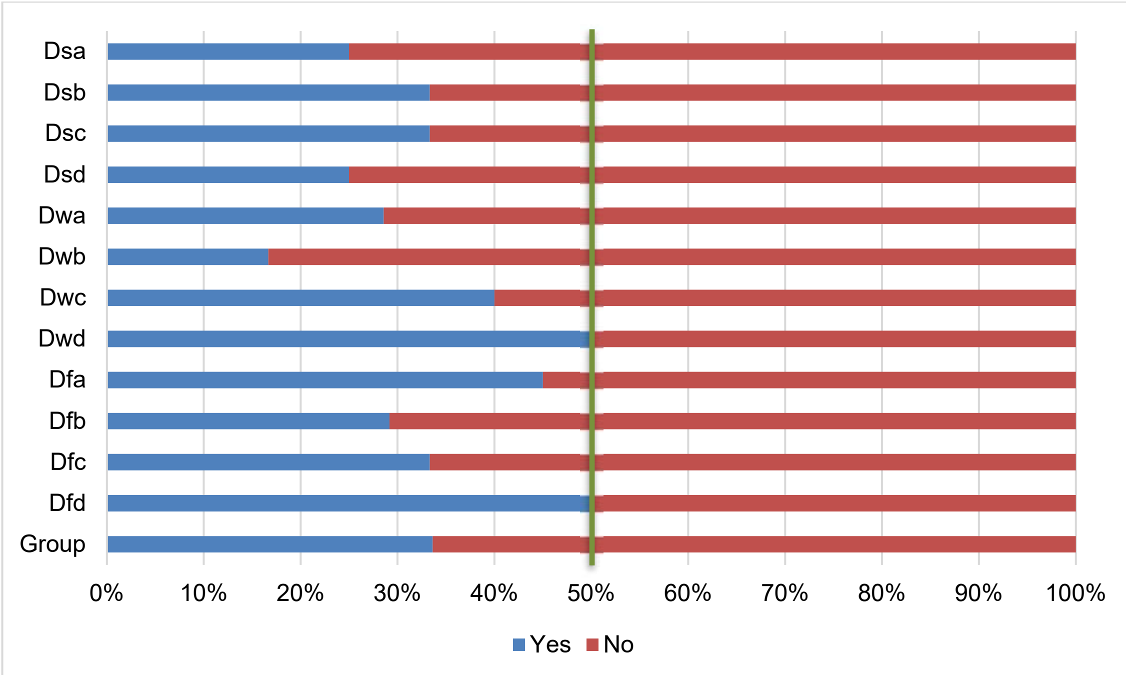


Figure 18. Do Indicators Perform Equally in Different Seasons in Continental Climates?

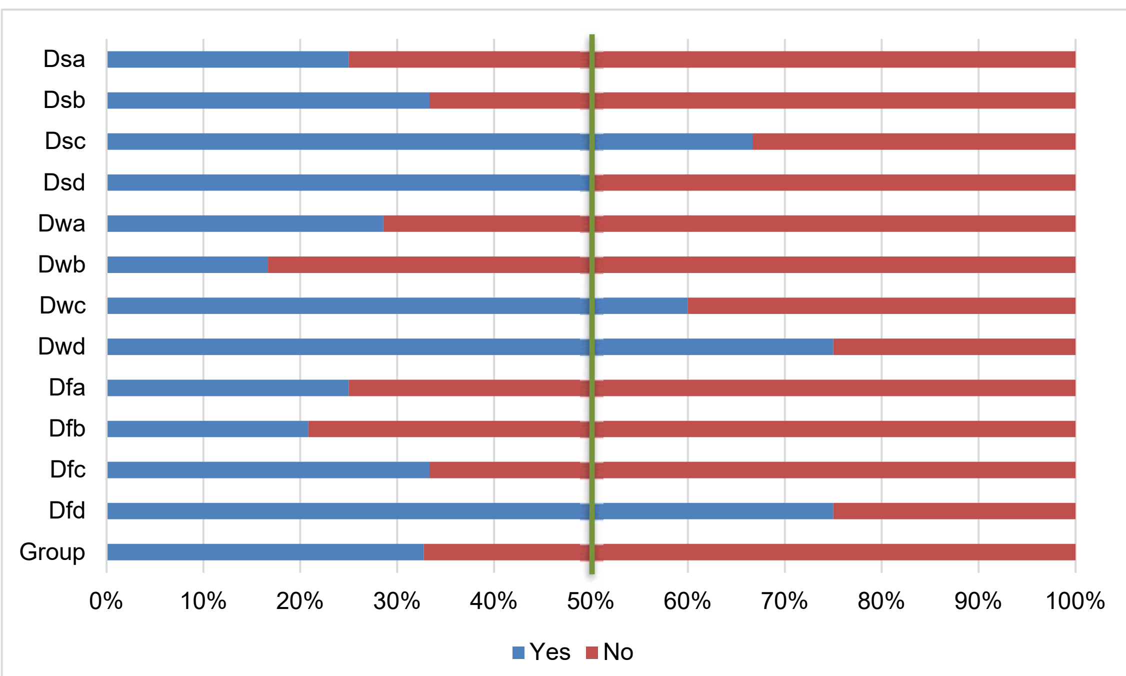


Table 38. Most Effective Indices and Indicators for Drought in Continental Climates

(a) Most effective indicators for *short-term* drought in continental climates

Category	Indicator	Köppen Climate Zone											
		Dsa	Dsb	Dsc	Dsd	Dwa	Dwb	Dwc	Dwd	Dfa	Dfb	Dfc	Dfd
Meteorology	Palmer Drought Severity Index	-	-	-	-	50%	-	-	-	-	-	-	-
	Palmer Z Index	-	-	-	-		57%	-	-	-	-	-	-
	Percent of Normal Precipitation	71%	69%	-	50%	50%	57%	-	-	77%	65%	-	71%
	Standardized Precipitation Evapotranspiration Index	57%	-	-	-	63%	71%	-	60%	59%		50%	57%
	Standardized Precipitation Index	71%	-	-	-	88%	86%	-	-	77%	65%	57%	71%
	Other (unspecified)	-	-	-	-	50%	-	-	-				
	Number of responses	14	13	3	4	8	7	5	5	22	23	14	4
Soil Moisture	Soil Moisture Deficit Index	-	-	-	-	-	50%	-	-	-	-	-	-
	Number of responses	14	12	3	4	8	7	5	5	21	23	14	4
Remote sensing	Normalized Difference Vegetation Index	-	-	-	-	-	-	-	60%	-	-	-	-
	Normalized Difference Water Index & Land Surface Water Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Vegetation Drought Response Index	-	-	67%	-	-	-	-	60%	-	-	-	-
	Number of responses	13	10	3	4	8	7	5	5	21	22	14	4
Composite or modeled	United States Drought Monitor	-	60%	50%	67%	63%	71%	75%	75%	67%	77%	69%	-
	Number of responses	13	10	2	3	8	7	4	4	21	22	13	3

(b) Most effective indicators for *long-term* drought in continental climates

Category	Indicator	Köppen Climate Zone											
		Dsa	Dsb	Dsc	Dsd	Dwa	Dwb	Dwc	Dwd	Dfa	Dfb	Dfc	Dfd
Meteorology	Palmer Drought Severity Index	54%	-	50%	-	71%	83%	-	-	62%	52%	-	-
	Palmer Z Index	-	-	50%	-	-	-	-	-			-	-
	Percent of Normal Precipitation	69%	58%	50%	67%	57%	67%	-	-	76%	61%	-	-
	Self-Calibrated Palmer Drought Severity Index	-	-	50%	-	-	-	-	-	-	-	-	-
	Standardized Precipitation Evapotranspiration Index	54%	-	50%	-	57%	83%	50%	67%	57%	-	54%	-
	Standardized Precipitation Index	69%	-	50%	67%	71%	83%	50%	-	57%	57%	54%	-
	Number of responses	13	12	2	3	7	6	4	3	21	23	13	3
Soil moisture	Evapotranspiration Deficit Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Soil Moisture Deficit Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Number of responses	13	11	3	4	7	6	5	4	20	23	14	4
Hydrology	Standardized Reservoir Supply Index	-	-	50%	-	-	-	-	-	-	-	-	-
	Number of responses	12	9	2	3	7	6	4	3	19	19	12	3
Remote sensing	Enhanced Vegetation Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Normalized Difference Vegetation Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Normalized Difference Water Index & Land Surface Water Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Vegetation Condition Index	-	-	-	50%	-	-	-	-	-	-	-	-
	Number of responses	11	8	3	4	7	6	5	4	19	20	13	4
Composite or modeled	Global Land Data Assimilation System	-	-	50%	-	-	-	-	-	-	-	-	-
	United States Drought Monitor	55%	50%	50%	67%	71%	67%	75%	67%	74%	81%	67%	-
	Number of responses	11	8	2	3	7	6	4	3	19	21	12	3

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Short-term drought is less than six months in duration. Long-term is six months or more in duration. Dsa (Humid Continental Climate-Dry Warm Summer); Dsb (Humid Continental Climate–Dry Cool Summer); Dsc (Continental Subarctic–Cold Dry Summer); Dsd (Continental Subarctic–Dry Summer with Very Cold Winter); Dwa (Humid Continental–Hot Summers with Dry Winters); Dwb (Humid Continental-Mild Summer with Dry Winters); Dwc (Subarctic with Cool Summers and Dry Winters); Dwd (Subarctic with Cold Winters and Dry Winters); Dfa (Humid Continental Hot Summers with Year-round Precipitation); Dfb (Humid Continental Mild Summer, Wet All Year); Dfc (Subarctic with Cool Summers and Year-round Precipitation); Dfd (Subarctic with Cold Winters and Year-round Precipitation).

Table 39. Most Effective Indices and Indicators for Drought in Continental Climates *not* listed in the WMO *Handbook of Drought Indicators and Indices*

Indicator	Köppen Climate Zone											
	Dsa	Dsb	Dsc	Dsd	Dwa	Dwb	Dwc	Dwd	Dfa	Dfb	Dfc	Dfd
5-day Forecasts	50%	-	-	-	57%	50%	-	-	-	-	-	-
8 to 14-day Forecasts	50%	-	-	-	57%	50%	-	-	50%	-	57%	-
30-day Forecasts	-	-	-	-	-	-	-	-	-	-	50%	50%
Crop Status	75%	56%	67%	75%	86%	83%	80%	75%	80%	83%	71%	75%
Groundwater depth	-	-	-	-	71%	67%	-	-	55%	-	-	-
Precipitation Departures from Normal	83%	67%	-	75%	57%	50%	60%	50%	75%	74%	79%	75%
Precipitation Percentiles	75%	67%	67%	75%	57%	67%	60%	50%	65%	70%	71%	50%
Precipitation Ranks	50%	56%	-	50%	-	50%	-	-	65%	65%	57%	-
Reported drought impacts	83%	67%	-	-	86%	83%	-	50%	75%	78%	86%	50%
Reservoir Storage	75%	78%	-	50%	71%	67%	60%	50%	60%	74%	64%	50%
Seasonal Forecasts	-	-	-	-	-	-	-	-	-	-	-	50%
Soil moisture	92%	89%	67%	75%	86%	83%	80%	75%	85%	87%	93%	75%
Streamflow	75%	67%	-	50%	86%	83%	60%	50%	75%	78%	64%	-
Temperature Departures from Normal	75%	67%	67%	50%	57%	67%	-	50%	75%	74%	86%	75%
Temperature Ranks	58%	56%	-	-	-	67%	-	-	60%	52%	57%	-
Vegetation Greenness	67%	67%	-	75%		50%	60%	50%	-	52%	-	-
Water Quality	-	-	-	-	-	-	-	50%	-	-	-	50%
Water Use (Demand)	75%	78%	-	75%	-	-	60%	50%	55%	57%	57%	50%
Wildfire Locations/Reports	-	-	-	-	57%	67%	-	-	-	-	-	-
Number of responses	12	9	3	4	7	6	5	4	20	23	14	4

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. Dsa (Humid Continental Climate-Dry Warm Summer); Dsb (Humid Continental Climate-Dry Cool Summer); Dsc (Continental Subarctic-Cold Dry Summer); Dsd (Continental Subarctic-Dry Summer with Very Cold Winter); Dwa (Humid Continental-Hot Summers with Dry Winters); Dwb (Humid Continental-Mild Summer with Dry Winters); Dwc (Subarctic with Cool Summers and Dry Winters); Dwd (Subarctic with Cold Winters and Dry Winters); Dfa (Humid Continental Hot Summers with Year-round Precipitation); Dfb (Humid Continental Mild Summer, Wet All Year); Dfc (Subarctic with Cool Summers and Year-round Precipitation); Dfd (Subarctic with Cold Winters and Year-round Precipitation).

Köppen Climate Group E: Polar Climates

Drought in North American polar climates

Climate group E is defined as polar climates with temperatures in the warmest months of less than 10°C. There are two climate zones in the group, based on the temperature of the warmest month (above or below 0°C), as follows (Heim, in litt.; Peel, Finlayson, & McMahon, 2007):

- ET: Tundra Climate
- EF: Ice Cap Climate

In North America, Köppen climate group E is restricted to parts of Alaska and higher elevations in the western United States, the Canadian far north and higher elevations in western Canada (Fig. 19). Of the 164 survey responses, seven respondents reported their geographic area of responsibility included Köppen climate group E. This included five for climate zone ET and two for EF. Four respondents were from Canada, and three were from the United States (Table 40). Although the polar climate zones were represented by few survey respondents, it is important to note that expertise in these climate zones is presumably restricted to a limited number of authorities.

All the climate group E respondents indicated their area of responsibility experienced drought in the prior 10 years (Table 41). The frequency of drought ranged from having occurred in one to more than five years out of the previous 10 (Table 42).

Typical drought duration ranged from one to more than 12 months long. No respondents reported drought that lasted less than one month in any of the group E climate zones. The majority (63%) of respondents indicated droughts typically lasted six months or more in each climate zone and would therefore be considered long-term (Table 43).

Factors affecting choice of indicators

The availability of relevant and required data was reported to be the most important factor when choosing indicators for polar climates by 100% of the survey respondents. Conversely, no respondents indicated the complexity or difficulty of the required calculation was important. The importance of the remaining factors was scored the same by all respondents: 75% for climate zone ET and 50% for zone EF (Table 44).

As previously noted, the polar climate zones were represented by few respondents. However, agreement by all the survey respondents with polar expertise may be considered noteworthy.

The most important factors when choosing indicators in polar climates, listed in order of importance (from most to least), were as follows:

- Availability of relevant and required data to calculate the indicator.
- Relevance of the indicator to the area or region, familiarity with the specific indicator, or the history of indicators used previously in the area or region (equally important).
- Complexity or difficulty of the required calculation.

Performance of indicators

The opinions of survey respondents were evenly split as to whether indicators performed equally well across their respective geographical areas of responsibility in polar climate zone ET. There were two respondents for climate zone EF, both of whom reported indicators did not perform equally well (Table 45). Most respondents reported indicators performed equally well across different seasons in climate zone ET and were equally split for climate zone EF (Table 46).

Drought indicators in North American polar climates

Nineteen indicators were scored as being very effective for monitoring short-term drought, and 12 were scored as being very effective for long-term drought (Table 47). However, most of the indicators were scored as very effective by only 50% of the respondents. One indicator that stands out is the USDM, which was scored as very effective by all the respondents for both short-term and long-term drought in both polar climate zones (Table 47).

Survey respondents scored 17 drought indicators that were not listed in the WMO Handbook as being very effective for monitoring drought in polar climates (Table 48).

As noted previously, the number of respondents who were able to provide experience for polar climate zones was quite small. Hence, it is challenging to form strong conclusions about the effectiveness of these indicators based on that sample size.

Figure 19. Distribution of Polar Climates in North America

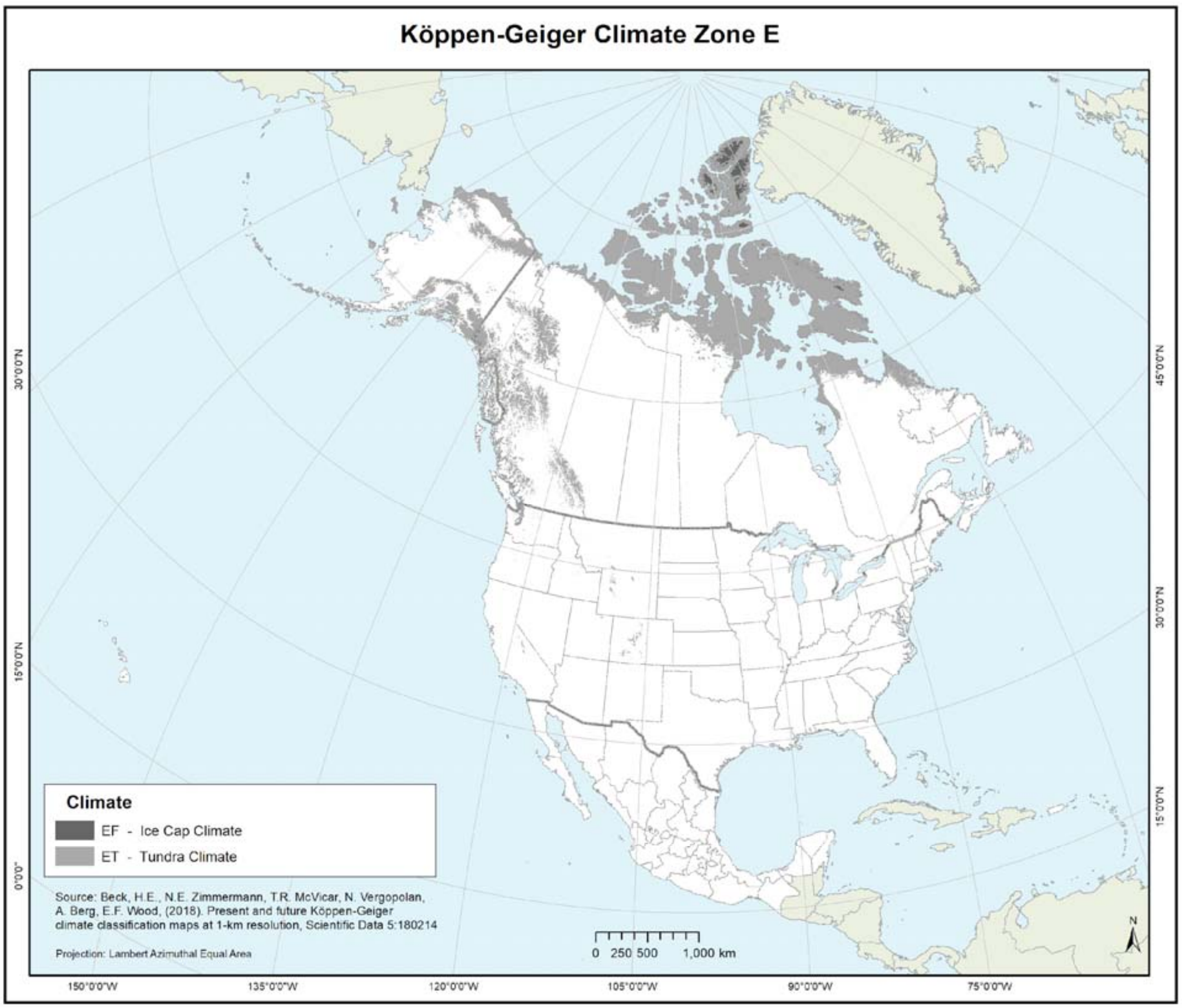


Table 40. Survey Respondents Active in Polar Climates, by Country

Climate Zone	Canada	Mexico	United States	Total
ET: Tundra Climate	3	-	2	5
EF: Ice Cap Climate	1	-	1	2
Total	4	-	3	7

Note: Data indicate the number of survey responses.

Table 41. Occurrence of Drought in Polar Climates, in the Past 10 years

Climate Zone	Yes	No	Do not know
ET: Tundra Climate	5	-	-
EF: Ice Cap Climate	2	-	-
Total	7	-	-

Note: Data indicate the number of survey responses.

Table 42. Frequency of Drought in Polar Climates

Climate Zone	Drought frequency (years)		
	1 – 2	3 – 5	5+
ET: Tundra Climate	1	2	2
EF: Ice Cap Climate	-	1	1
Total	1	3	3

Notes: Data indicate the number of survey responses. Drought frequency refers to how often drought was experienced in the past 10 years.

Table 43. Duration of Typical Drought in Polar Climates

Climate Zone	Drought duration (months)				Short-term drought	Long-term drought
	1 – 3	3 – 6	6 – 12	12+		
ET: Tundra Climate	1	1	1	2	2	3
EF: Ice Cap Climate	-	1	1	1	1	2
Total	1	2	2	3	3	5

Notes: Data indicate the number of survey responses, which differed for long-term drought and short-term drought. Short-term drought is less than six months in duration. Long-term is six months or more in duration.

Table 44. Factors Affecting Choice of Indicators in Polar Climates

Factors	Köppen Climate Zone	
	ET	EF
Availability of required data to calculate the indicator	100%	100%
Complexity or difficulty of the required calculation	-	-
Relevance of the indicator to the area/region	75%	50%
Familiarity with the specific indicator	75%	50%
History of indicators used previously in the area or region	75%	50%
Number of responses	4	2

Notes: Data indicate where at least 50% of the survey respondents scored the factor as very important for the respective climate zone. ET (Tundra Climate); EF (Ice Cap Climate).

Table 45. Performance of Indicators Across Geographical Area in Polar Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
ET - Tundra Climate	2	2
EF - Ice Cap Climate	-	2
Total	2	4

Note: Data indicate the number of survey responses.

Table 46. Performance of Indicators Across Different Seasons in Polar Climates

Climate Zone	Indicators perform equally well	Indicators do not perform equally well
ET - Tundra Climate	3	1
EF - Ice Cap Climate	1	1
Total	4	2

Note: Data indicate the number of survey responses.

Table 47. Most Effective Indices and Indicators for Drought in Polar Climates

(a) Most effective indicators for *short-term* drought in polar climates

Category	Indicator	Köppen Climate Zone	
		ET	EF
Meteorology	Crop Moisture Index	-	50%
	Palmer Drought Severity Index	50%	50%
	Palmer Z Index	-	50%
	Self-Calibrated Palmer Drought Severity Index	-	50%
	Standardized Precipitation Evapotranspiration Index	50%	50%
	Standardized Precipitation Index	50%	50%
	Number of responses	4	2
Soil moisture	Evapotranspiration Deficit Index	-	50%
	Soil Moisture Deficit Index	-	50%
	1-Actual Evapotranspiration/Potential Evapotranspiration*	-	50%
	Number of responses	4	2
Hydrology	Palmer Hydrological Drought Index	-	100%
	Surface Water Supply Index	67%	100%
	Number of responses	3	1
Remote sensing	Enhanced Vegetation Index	-	50%
	Evaporative Stress Index	-	50%
	Normalized Difference Vegetation Index	50%	100%
	Normalized Difference Water Index & Land Surface Water Index	-	50%
	Vegetation Condition Index	-	50%
	Vegetation Drought Response Index	50%	100%
	Vegetation Health Index	-	50%
	Number of responses	4	2
Composite or modeled	United States Drought Monitor	100%	100%
	Number of responses	3	1

(b) Most effective indicators for *long-term* drought in polar climates

Category	Indicator	Köppen Climate Zone	
		ET	EF
Meteorology	Palmer Drought Severity Index	67%	100%
	Standardized Precipitation Evapotranspiration Index	67%	100%
	Standardized Precipitation Index	67%	100%
	Number of responses	3	1
Soil moisture	Evapotranspiration Deficit Index	-	50%
	Soil Moisture Deficit Index	-	50%
	Number of responses	4	2
Hydrology	Palmer Hydrological Drought Index	-	100%
	Number of responses	3	1
Remote sensing	Enhanced Vegetation Index	-	50%
	Normalized Difference Vegetation Index	-	50%
	Normalized Difference Water Index & Land Surface Water Index	-	50%
	Vegetation Condition Index	-	50%
	Vegetation Drought Response Index	-	50%
	Number of responses	4	2
Composite or modeled	United States Drought Monitor	100%	100%
	Number of responses	3	1

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. ET (Tundra Climate); EF (Ice Cap Climate). *The original selection of indicators listed in the survey did not include 1-AET/PET. However, respondents could provide "other" indicators they had found to be effective in their geographic range of responsibility.

Table 48. Most Effective Indices and Indicators for Drought in Polar Climates *not* listed in the WMO *Handbook of Drought Indicators and Indices*

Indicator	Köppen Climate Zone	
	ET	EF
5-day Forecasts	50%	-
8 to 14-day Forecasts	100%	-
Crop Status	50%	100%
Groundwater Depth	75%	50%
Precipitation Departures from Normal	75%	50%
Precipitation Percentiles	50%	100%
Precipitation Ranks	75%	50%
Reported Drought Impacts	75%	50%
Reservoir Storage	50%	50%
Seasonal Forecasts	75%	-
Soil Moisture	75%	100%
Streamflow	75%	50%
Temperature Departures from Normal	50%	50%
Temperature Ranks	50%	50%
Vegetation Greenness	75%	100%
Water Quality	50%	50%
Water Use/Demand	75%	50%
Number of responses	4	2

Notes: Data indicate where at least 50% of the survey respondents scored the indicator as very important for the respective climate zone. ET (Tundra Climate); EF (Ice Cap Climate).

Drought in North America

Defining drought

Drought is a difficult concept to define. Participants in the online webinars held in October 2020 were asked to discuss how they define drought in their geographic areas of responsibility or economic sectors.

Participants noted the "textbook" definitions of drought, such as "lack of moisture and the amount of moisture deficit" or "a deficiency of precipitation over an extended period." But most of the discussion focused on recognizing drought based on the information provided by drought indicators. The use of Standardized Precipitation and Evapotranspiration Index (SPEI) and Surface Water Supply Index to define drought was mentioned by several participants. It was also noted that drought could be forecast by expected precipitation and temperature month to month; current snowpack and forecast snowpack; watershed moisture conditions (groundwater, soil moisture monitoring) and customer water demand. One participant noted that authorities in British Columbia (Canada) use the 30-day percent of average precipitation and the 7-day average streamflow percentile as indicators of drought. Another explained they used watershed-specific drought indicators, based on storage levels in a system of four reservoirs.

In summary, most drought practitioners are familiar with the generic definitions of drought. But drought can be perceived differently depending on what climatological region is being observed, the primary goal in describing it, and the available data.

Frequency and duration of drought in North America

Almost all the online survey respondents reported their areas of responsibility had experienced drought in the past 10 years. Out of 133 responses, only four (two from Canada and two from the United States) had not experienced drought in the past decade and 11 indicated they did not know (Table 49). Most Canadian and US respondents indicated that, in their experience, drought had occurred five or fewer years out of the past 10. In contrast, most Mexican respondents reported that drought had occurred in more than five of those years (Table 50).

Typical drought durations ranged from one to more than 12 months long in North America. No respondents reported drought that lasted less than one month. More than half of respondents from all three countries, including more than 80% of the Canadians and Mexicans, indicated that drought was typically short-term. In comparison, only 54% of US respondents reported that drought was typically short-term (Table 51, Fig. 20).

Factors affecting choice of indicators in North America

Most of the survey respondents from all three countries indicated that the availability of relevant and required data to calculate the indicator was a very important factor when choosing indicators. This was the only factor considered very important by respondents from all three countries, and also the only factor considered very important by Mexican respondents. Conversely, the complexity or difficulty of the required calculation was not considered very important by most respondents from all three countries. The relevance of the indicator to the area or region, familiarity with the specific indicator, and the history of indicators used previously in the area or region were each considered very important to Canadian and US authorities (Table 52).

Multiple survey respondents commented that a major factor in their choice of indicator or indices was how "location-specific" they are. As states and provinces differ, so do their standards and techniques for monitoring drought. Some respondents noted that indicators are prescribed by the state or provincial authority. This makes it challenging for indicators to transcend boundary lines where drought jurisdictions differ. This suggests efforts to encourage communication between drought authorities across boundary lines could be beneficial. Developing more universally accepted methodology for monitoring and managing drought could streamline the decision-making process when it comes to selecting appropriate indicators. This could be particularly important in areas at high risk of drought that transect political boundaries where two or more authorities are required to collaborate.

Comments also mentioned that being able to "correlate the indicator with the actual conditions in the field" would be desirable. The need to be able to visualize drought at both a state (or provincial) and local level was also highlighted. These features would improve decision-making in which real-time drought conditions would better inform which indicators could or should be used.

Performance of indicators in North America

Most survey respondents from each country agreed that indicators do not perform equally well across the geographic areas of concern. However, opinions were almost evenly split for Mexican and US respondents (Table 53).

Survey respondents reported that indicators perform equally well in the varied geographical terrains of four climate zones: Af, Cwa, Cwc and Cfc. For all other climate zones, respondents indicated that this was not the case: that indicators do not perform equally well across their respective geographical areas (or were equally split) (Fig. 21). This was because, as most commented, the geography in their areas of responsibility were highly variable. Choosing indicators that would be effective throughout the area was highly challenging. This emphasizes the importance of establishing a library of indicators that are effective for specific climate zones.

A recurring issue regarding streamflow and soil conditions was also noted by survey respondents. There were suggestions that streamflow monitoring can be ineffective due to the limited timeframes for which data are available (e.g., 7 or 28-day data). One respondent commented that it is also unreliable when "…there is little baseflow or flow is not closely representative of impacts to agriculture." Regarding soil moisture indicators, respondents commented that soil conditions can vary greatly throughout a region and certain indicators do not account for this.

Survey respondents also reported that indicators did not perform equally well across different seasons, although (again) the opinions were almost evenly split for Mexican and US respondents (Table 54). They reported that indicators perform equally well throughout different seasons in the three tropical climate zones (Af, Am, Aw), in Cwa, and in five subarctic or polar climate zones (Dsc, Dwc, Dwd, Dfd and ET). For all other climate zones, respondents indicated that indicators do not perform equally well (or were split) across different seasons (Fig. 22).

Respondents indicated that seasonal variability makes certain indicators unreliable at different times of the year. Dry seasons and winter seasons were both specifically mentioned as being problematic due to the inability to use vegetation and water flow indicators. The challenges with vegetation and crop measurement indicators also arose frequently.

Being able to select indicators based on the current season could improve the efficacy of drought monitoring. This level of detail may be more important for monitoring and managing drought in certain geographic areas or climate groups than others. It is also likely that each authority will have knowledge of seasonal drought indicators within their respective areas of responsibility, which could be included when cataloging drought indicators.

The availability of data was frequently mentioned by survey respondents as a barrier to knowing how well certain indicators function. Some key indicators lack data, either because of a lack of input or because of their inability to record the data effectively. One respondent stated, "data are not shared among different agencies." Data sharing across borders—or between relevant authorities—could improve decision making by allowing more reliable information with which the analysts can work.

Two respondents stated the condition of measuring instruments was key to the ability of indicators to work year-round. It was implied that maintenance of measuring instruments varied, and harsh winter conditions can be damaging to equipment. This may be an important factor when considering the use of indicators in extreme climate regions, particularly those which fluctuate from hot summers to cold winters.

Effectiveness of drought indicators in North America

Based on the opinions of survey respondents, the regional effectiveness of drought indicators included in the WMO handbook differs substantially from that of indicators not so listed.

Survey respondents indicated that most of the WMO handbook indicators were not very effective for most climate zones. Only four out of 44 indicators were considered very effective in at least half of the different climate zones (Tables 10, 19, 28, 29, 38 and 47). In contrast, 12 out of the 21 indicators that were not listed in the WMO handbook were scored as being very effective in at least half of the different climate zones (Tables 11, 20, 30, 39 and 48).

The WMO handbook indicators that were considered very effective in the most different climate zones were PNP, SPEI, SPI and the USDM. However, none were assessed as very effective in every North American climate zone. For short-term drought, SPI was scored as very effective for 27 out of the 34 North American climate zones, PNP for 23, and SPEI for 22. Collectively, these three meteorology indicators were scored as very effective for short-term drought in 32 out of 34 climate zones, as was the USDM (Tables 10, 19, 28, 38 and 47).

SPI was considered very effective for long-term drought in 29 climate zones. The other three indicators scored slightly poorer for long-term drought: PNP was considered very effective for 21 climate zones, SPEI for 17, and the USDM was scored as very effective for long-term drought in 30 climate zones. It is worth noting that for many climate zones, PNP and SPEI were considered very effective by only 50% of the respondents (Tables 10, 19, 28, 29, 38 and 47). Based on the opinions of survey respondents, SPI and the USDM may be considered the most regionally effective drought indicators that were listed in the WMO handbook

The 13 indicators not listed in the WMO handbook that were scored as very effective for most climate zones were Crop Status, Groundwater Depth, Precipitation Departures from Normal, Precipitation Percentiles, Precipitation Ranks, Reported Drought Impacts, Reservoir Storage, Soil Moisture, Streamflow, Temperature Departures from Normal, Temperature Ranks, Vegetation Greenness, and Water Use (Demand). Soil Moisture was notable for being the only indicator scored as very effective in every North American climate zone. And this indicator was scored as such by substantial majorities of the respondents for each zone. Two other indicators—Crop Status and Reservoir Storage—were each scored as very effective for 33 out of 34 climate zones (Tables 11, 20, 30, 39 and 48). These results suggest it would be valuable to include these indicators in any future revision of the WMO *Handbook of Drought Indicators and Indices*.

Percent of Normal Precipitation

PNP involves a simple calculation that can be used to compare any period for a given location. It does not provide information on how rare a precipitation event is. SPI, in contrast, uses historical precipitation records to calculate a probability of precipitation for periods of one to 48 months for a given location. SPI, therefore, has a greater breadth of application than PNP (Heim, in litt.).

The positive ranking of PNP by survey respondents for most North American climate zones was explored during the project webinars. Participants were asked about their familiarity with PNP, why this drought indicator was important compared to other indicators, and how it helps the understanding of drought (see Methods).

Participants noted PNP is widely understood even by non-experts. The calculation is simple, and this makes it easy for people to understand and communicate. It allows an investigator to make an initial review of conditions in a specific area and helps in deciding whether other indicators should be engaged. However, participants also suggested that, while it helps to understand the basic occurrence of an event, it does not elucidate what is occurring over time. It does not account for data irregularities caused by meteorological phenomena (e.g., storms), and is not effective for agricultural production since annual rainfall could occur over very few occasions, leaving plants to be under stress at other times because they do not have water with the appropriate frequency.

Table 49. Occurrence of Drought in North America, in the Past 10 years

Country	Yes	No	Do not know
Canada	24	2	3
Mexico	18	2	6
United States	76	-	2
Total	118	4	11

Note: Data indicate the number of survey responses.

Table 50. Frequency of Drought in North America

Country	Drought frequency (years)			
	1 – 2	3 – 5	5+	Do not know
Canada	7	7	4	1
Mexico	4	11	34	-
United States	14	20	6	3
Total	25	38	44	4

Notes: Data indicate the number of survey responses. Drought frequency refers to how often drought was experienced in the past 10 years.

Table 51. Duration of Typical Drought in North America

Country	Drought duration (months)				Short-term drought	Long-term drought
	1 – 3	3 – 6	6 – 12	12+		
Canada	8	8	1	2	16	3
Mexico	5	10	1	1	15	2
United States	14	24	11	21	38	32
Total	27	42	13	24	69	37

Notes: Data indicate the number of survey responses, which differed for long-term drought and short-term drought. Short-term drought is less than six months in duration. Long-term is six months or more in duration.

Figure 20. Duration of Typical Drought in North America

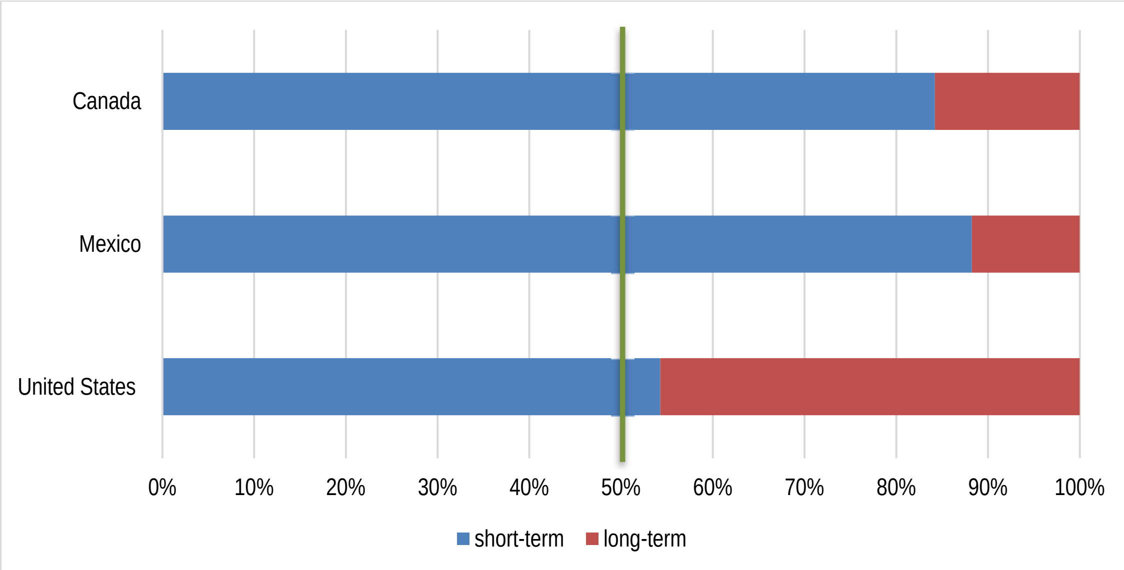


Table 52. Factors Affecting Choice of Indices and Indicators in North America

Index/indicator	Canada	Mexico	United States
Availability of required data to calculate the indicator	69%	67%	62%
Complexity or difficulty of the required calculation	-	-	-
Relevance of the indicator to the area/region	69%	-	75%
Familiarity with the specific indicator	62%	-	71%
History of indicators used previously in the area or region	62%	-	58%
Number of responses	13	55	9

Table 53. Performance of Indicators Across Geographical Area of Responsibility in North America

Country	Indices and indicators perform equally well	Indices and indicators do not perform equally well
Canada	5	12
Mexico	4	5
United States	26	30
Total	35	47

Note: Data indicate the number of survey responses.

Table 54. Performance of Indicators Across Different Seasons in North America

Country	Indices and indicators perform equally well	Indices and indicators do not perform equally well
Canada	6	11
Mexico	5	4
United States	27	29
Total	38	44

Note: Data indicate the number of survey responses.

Figure 21. Do Indicators Perform Equally Across Geographical Areas of Responsibility, by Climate Zone?

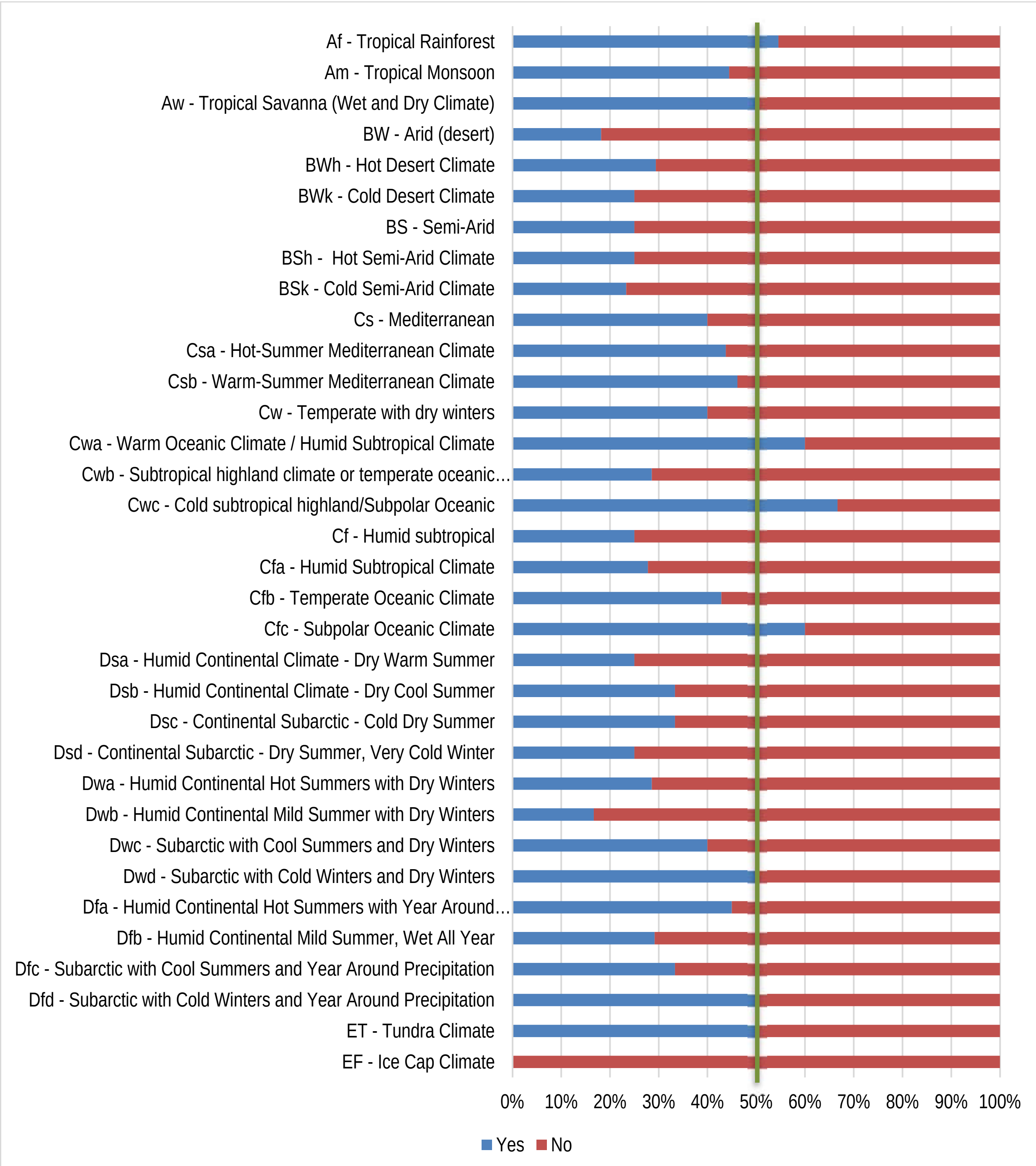
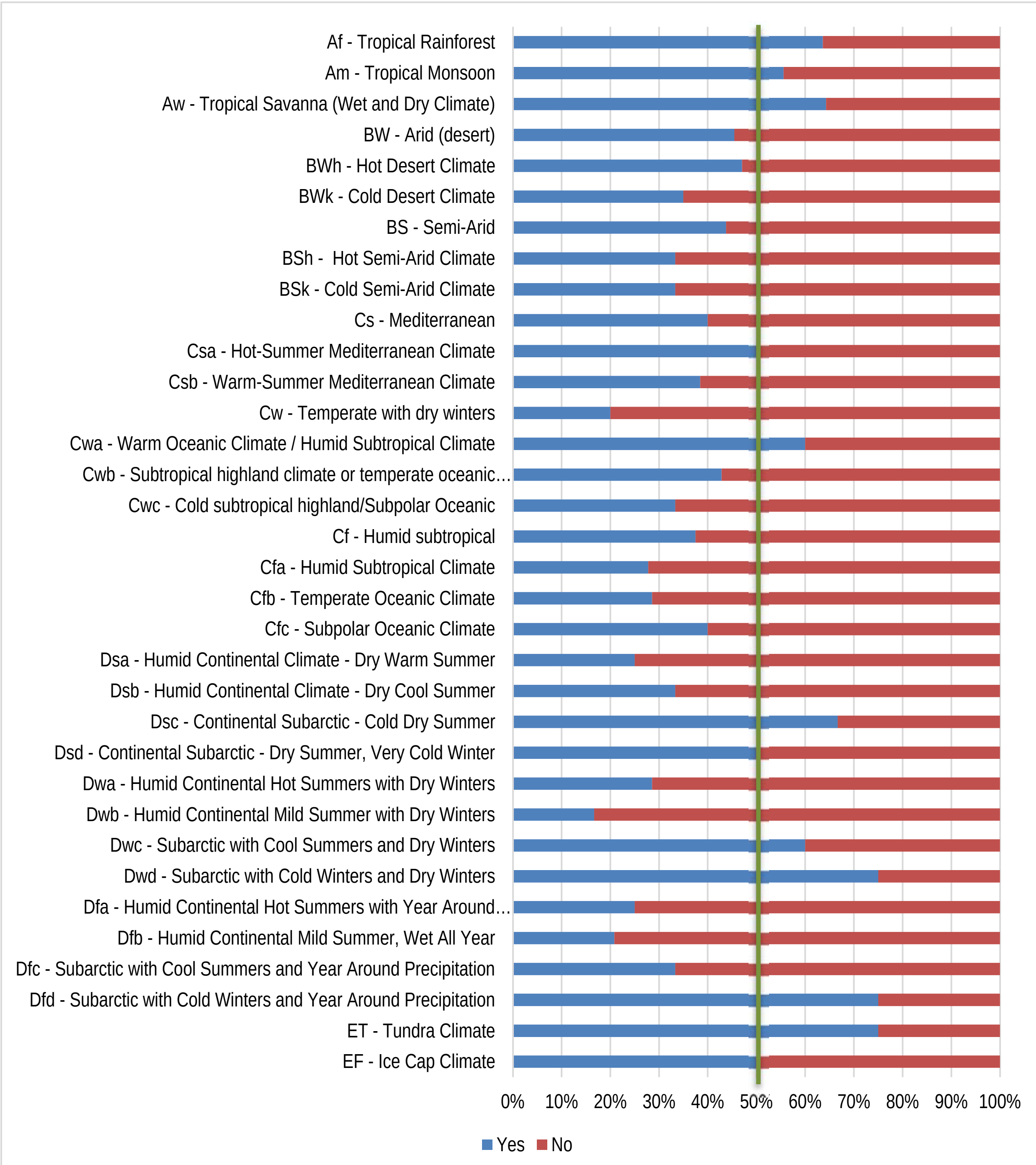


Figure 22. Do Indicators Perform Equally Across Different Seasons, by Climate Zone?



Bibliography

Arnfield, A. J. (2020). *Köppen climate classification*. Encyclopædia Britannica Online. https://www.britannica.com/science/Koppen-climate-classification. September 08, 2020.

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., & Wood, E. F. (2018). *Present and future Köppen-Geiger climate classification maps at 1-km resolution*. Scientific data, 5, 180214. https://doi.org/10.1038/sdata.2018.214.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). *Updated world map of the Köppen–Geiger climate classification*. Hydrol. Earth Syst. Sci. 11 (5): 1633–1644.

WMO & GWP. (2016). *Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs)*. Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.

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Appendix A. Köppen climate classification

The original Köppen climate descriptions have been revised by different authors and may vary from different sources. Also, some descriptions used in the online survey were edited for brevity and may not match the text presented below. Any differences are minor and not significant to the study results.

Tropical climates (group A)	
Classification	Description
Af	Tropical Climate with Rain Year-round
Am	Tropical Climate with Seasonally Excessive Rainfall
Aw	Tropical Savanna Climate with Dry Winters

Dry climates (group B)	
Classification	Description
BW	Arid (desert) Climate
BWh	Hot Desert Climate
BWk	Cold Desert Climate
BS	Semi-arid Climate
BSh	Hot Semi-arid Climate
BSk	Cold Semi-arid Climate

Temperate climates (group C)	
Classification	Description
Cs	Mediterranean (Mild Winters and Dry Summers) Climate
Csa	Mediterranean Climate with Hot Summers
Csb	Mediterranean Climate with Mild Winters and Short, Warm, Dry Summers
Cw	Temperate Climate with Mild and Dry Winters
Cwa	Temperate Climate with Hot Summers
Cwb	Temperate Climate with Warm Summers
Cwc	Temperate Climate with Cool Summers
Cf	Humid Temperate Climate
Cfa	Hot-Summer Humid Subtropical Climate
Cfb	Humid Temperate Climate with Warm Summers
Cfc	Humid Temperate Climate with Cool Summers

Continental climates (group D)	
Classification	Description
Dsa	Continental Climate with Hot Dry Summers
Dsb	Continental Climate with Warm Dry Summers
Dsc	Continental Climate with Cool Dry Summers
Dsd	Continental Climate with Dry Summers and Very Cold Winters
Dwa	Continental Climate with Hot Summers and Dry winters
Dwb	Continental Climate with Warm Summers and Dry Winters
Dwc	Continental Climate with Cool Summers and Dry Winters
Dwd	Continental Climate with Dry, Very Cold Winters
Dfa	Humid Continental Climate with Hot Summers and Precipitation Year-round
Dfb	Humid Continental Climate with Mild Summers and Precipitation Year-round
Dfc	Subarctic Climate with Cool Summers and Precipitation Year-round
Dfd	Subarctic Climate with Very Cold Winters and Precipitation Year-round

Polar climates (group E)	
Classification	Description
ET	Tundra Climate
EF	Ice Cap Climate

Sources: adapted from Arnfield (2020); Beck et al. (2018); and Heim (in litt.).

Appendix B. Indices and indicators

The following provides a complete list of the drought indicators that were reviewed by participants in the CEC online survey that provided data for this report.

Meteorology Indices and Indicators	
Agricultural Reference Index for Drought (ARID)	NOAA Drought Index (NDI)
Aridity Anomaly Index (AAI)	Palmer Drought Severity Index (PDSI)
Aridity Index (AI)	Palmer Z Index (PZI)
China Z Index (CZI)	Percent of Normal Precipitation (PNP)
Crop Moisture Index (CMI)	Rainfall Anomaly Index (RAI)
Crop-specific Drought Index (CSDI)	Reclamation Drought Index (RDI)
Deciles	Self-Calibrated Palmer Drought Severity Index (sc-PDSI)
Drought Area Index (DAI)	Standardized Anomaly Index (SAI)
Drought Reconnaissance Index (DRI)	Standardized Precipitation Evapotranspiration Index (SPEI)
Effective Drought Index (EDI)	Standardized Precipitation Index (SPI)
Hydro-thermal Coefficient of Selyaninov (HTC)	Weighted Anomaly Standardized Precipitation (WASP)
Keetch–Byram Drought Index (KBDI)	
Soil Moisture Indices and Indicators	
1-Actual Evapotranspiration/Potential Evapotranspiration (1-AET/PET)	Soil Moisture Deficit Index (SMDI)
Evapotranspiration Deficit Index (ETDI)	Soil Water Storage (SWS)
Soil Moisture Anomaly (SMA)	
Hydrology Indices and Indicators	
Aggregate Dryness Index (ADI)	Standardized Streamflow Index (SSFI)
Palmer Hydrological Drought Index (PHDI)	Standardized Water-level Index (SWI)
Standardized Reservoir Supply Index (SRSI)	Streamflow Drought Index (SDI)
Standardized Snowmelt and Rain Index (SMRI)	Surface Water Supply Index (SWSI)
Remote Sensing Indices and Indicators	
Enhanced Vegetation Index (EVI)	Temperature Condition Index (TCI)
Evaporative Stress Index (ESI)	Vegetation Condition Index (VCI)
Normalized Difference Vegetation Index (NDVI)	Vegetation Drought Response Index (VegDRI)
Normalized Difference Water Index (NDWI) & Land Surface Water Index (LSWI)	Vegetation Health Index (VHI)
Soil Adjusted Vegetation Index (SAVI)	Water Requirement Satisfaction Index (WRSI & Geo-spatial WRSI)
Composite or Modeled Indices and Indicators	
Combined Drought Indicator (CDI)	Multivariate Standardized Drought Index (MSDI)
Global Integrated Drought Monitoring and Prediction System (GIDMaPS)	United States Drought Monitor (USDM)
Global Land Data Assimilation System (GLDAS)	

Not Included in the WMO *Handbook of Drought Indicators and Indices*	
5-day Forecasts	Reservoir Storage
8 to 14-day Forecasts	Seasonal Forecasts
30-day Forecasts	Soil Moisture
Crop Status	Streamflow
Groundwater Depth	Temperature Departures from Normal
Local Burn Bans	Temperature Ranks
Media Reports	US Drought Outlook
Precipitation Departures from Normal	Vegetation Greenness
Precipitation Percentiles	Water Quality
Precipitation Ranks	Water Use (Demand)
Reported Drought Impacts	Wildfire Locations /Reports

Appendix C. Survey questions

1. In which country do you currently work?
2. In which federal district, state, territory or region in the United States do you work? Select all that apply.
3. In which province or territory in Canada do you work? Select all that apply.
4. In which federal entity or state in Mexico do you work? Select all that apply.
5. What is the name of the town or city where you currently work? If you do not work in a city or town, please enter the closest city or town to your work location.
6. For which federal district, state, territory, or region in the United States are you responsible?
7. For which province or territory in Canada are you responsible? Select all that apply.
8. For which federal entity or state in Mexico are you responsible? Select all that apply.
9. In the past 10 years, has your geographical area of responsibility experienced drought?
10. Overall, in the last 10 years, how often has your geographical area of responsibility experienced drought?
11. In your geographical area of responsibility, what is the duration (in months) of a typical drought?
12. Currently, how concerned are you about drought occurring in your geographical area of responsibility? Score from 1 (Not Concerned) to 5 (Extremely Concerned).
13. Do you currently have an official role in drought management and/or monitoring? For example, determining water usage or monitoring indicators or indices.
14. In what sector do you play a role in relation to drought?
15. What is the total population size of the geographical area(s) for which you are responsible?
16. How much time do you currently spend working in the following activities?
17. Drought is a complex phenomenon that is difficult to define. The climatological community classifies drought into the following 5 types:
    a. Meteorological: when dry weather patterns dominate an area.
    b. Hydrological: when low water levels become evident in streams, reservoirs and groundwater.
    c. Agricultural: when crops become affected.
    d. Socioeconomic: when the supply and demand of commodities are impacted.
    e. Ecological: when terrestrial and aquatic ecosystems are impacted.

    What impact does each of these types of drought have in your geographic area of responsibility? Score from 1 (no impact) to 5 (high impact).
18. The Köppen classification system divides climates into five main groups. Which Köppen climate zone(s) apply(ies) to your geographical area(s) of responsibility? Select all that apply.
19. Do you currently use the WMO *Handbook of Drought Indicators and Indices* in your work?
20. For short-term drought: In relation to your geographical area of responsibility, score each of the following METEOROLOGY indices and indicators from less effective (1) to very effective (5).
21. For long-term drought: In relation to your geographical area of responsibility, score each of the following METEOROLOGY indices and indicators from less effective (1) to very effective (5).

22. For short-term drought: In relation to your geographical area of responsibility, score each of the following SOIL MOISTURE indices and indicators from less effective (1) to very effective (5).
23. For long-term drought: In relation to your geographical area of responsibility, score each of the following SOIL MOISTURE indices and indicators from less effective (1) to very effective (5).
24. For short-term drought: In relation to your geographical area of responsibility, score each of the following HYDROLOGY indices and indicators from less effective (1) to very effective (5).
25. For long-term drought: In relation to your geographical area of responsibility, score each of the following HYDROLOGY indices and indicators from less effective (1) to very effective (5).
26. For short-term drought: In relation to your geographical area of responsibility, score each of the following REMOTE SENSING indices and indicators from less effective (1) to very effective (5).
27. For long-term drought: In relation to your geographical area of responsibility, score each of the following REMOTE SENSING indices and indicators from less effective (1) to very effective (5).
28. For short-term drought: In relation to your geographical area of responsibility, score each of the following COMPOSITE OR MODELED indices and indicators from less effective (1) to very effective (5).
29. For long-term drought: In relation to your geographical area of responsibility, score each of the following COMPOSITE OR MODELED indices and indicators from less effective (1) to very effective (5).
30. What factors affect your choices of indices and indicators to use in your geographical area of responsibility? Score each of the following from low importance (1) to high importance (5).
31. Do the indicators and indices you use perform equally well across your geographical area of responsibility?
32. If "No" [to question 31] please explain:
33. Do the indicators and indices you use perform equally well during different seasons of the year in your geographical area of responsibility?
34. If "No" [to question 33] please explain:
35. The following indicators are not included in the WMO *Handbook of Drought Indicators and Indices*. In relation to your geographical area of responsibility, please score each from 1 (low importance) to 5 (high importance).
36. Are there any OTHER indicators that you use to monitor drought in your geographical area of responsibility? Please explain.
37. Drought can have multiple overlapping impacts on human life and the environment. These impacts may be economic, ecological, and/or social. In relation to your geographical area of responsibility, please score each of the following ECONOMIC impacts from low impact (1) to high impact (5).
38. In relation to your geographical area of responsibility, please score each of the following ENVIRONMENTAL impacts from low impact (1) to high impact (5).
39. In relation to your geographical area of responsibility, please score each of the following SOCIAL impacts from low impact (1) to high impact (5).
40. Do you have any additional comments?
41. Optional. Please provide your: name, email, affiliation.