MEMORANDUM

Date: October 22, 2020

To: Andrea McNamara Doyle, Office of Chehalis Basin

From: Guillaume Mauger, PhD, Climate Impacts Group; Larry Karpack, PE, Watershed Science and Engineering; Bob Montgomery, PE, Anchor QEA, LLC

Cc: Chrissy Bailey, Office of Chehalis Basin; Jim Kramer and Ken Ghalambor, Office of Chehalis Basin consultant staff; Heather Page, Anchor QEA, LLC

Re: Local Actions Program Near-term Technical Analyses for Office of Chehalis Basin: Climate Change Modeling Options

Overview

This memorandum summarizes how climate change has been included in the Chehalis Basin Strategy and provides options on climate change modeling in the Chehalis Basin that could be used in the evaluation of a Local Actions Program. These options may be modified based on input from the Technical Advisory Group at the direction of the Office of Chehalis Basin (OCB) prior to consideration by the Chehalis Basin Board.

The Chehalis Basin Board has provided guidance for how they will evaluate a Local Actions Program. Specific to climate change, the Board directed that a Local Actions Program will plan for the 100-year flood conditions that are predicted for 2080 when considering outcomes and actions. In the near term, the Board has expressed a desire to better understand, and be able to describe to the public, what the 100-year flood conditions are predicted to be in 2080 that the Local Actions Program would be seeking to address. In other words, what should the Board assume now, for its initial planning purposes, that the basin's 100-year floodplain will look like in 2080? This planning assumption provides the foundation for all of the outcome measures agreed to by the Chehalis Basin Board. This will also focus their initial evaluation on what kinds of actions can most feasibly reduce risks associated with this expanded floodplain of the future. In the future, as actions under the Chehalis Basin Strategy are designed and implemented, and climate science continues to evolve, climate change predictions would likely need to be revisited.

Timing is an important consideration in evaluating how climate change should be used in the Board's consideration of a Local Actions Program: what can be completed in the next few months and what makes the most sense over a long-term period of time. For example, to evaluate the impacts on land use management changes in the potential 2080 time frame, information from climate change would have to be available within the next few months. In contrast, implementing actions recommended by the Board that will occur over the next several years may require more extensive evaluation of potential future floodplain changes caused by climate predictions.

The memorandum is organized as follows:

1. Summary of methodologies and assumptions from the State Environmental Policy Act (SEPA) Draft Environmental Impact Statement (EIS) regarding climate change modeling and scenarios. As reference, the SEPA Draft EIS evaluated a proposed flood retention facility and associated temporary reservoir on the Chehalis River, and changes to the Chehalis-Centralia Airport levee (the "project").
2. Summary of the University of Washington's Climate Impacts Group (CIG) recommendations on adjustments that could be made to climate change modeling (as stated in their SEPA Draft EIS comment letter).
3. Response to comments regarding climate change modeling performed for the SEPA Draft EIS by Natural Systems Design (NSD).
4. Options for what, if any, changes to the climate change assumptions and methodologies could be made for potential incorporation into future hydrologic and hydraulic modeling for a Local Actions Program.

Please note that this memorandum does not represent a formal response to comments on the SEPA Draft EIS. This information is being provided to inform the Chehalis Basin Board's evaluation of a Local Actions Program.

Summary of Options

In the near term, for the next couple of months during the Board's initial evaluation of a Local Actions Program's potential to address damage from 100-year flood events in 2080, a 26% increase for flood flows could be used while also exploring the impacts of larger changes by testing the effect of other scale factors (e.g., 50% increase).

In the longer term, the basin-wide hydrologic model[1] could be refined to improve flow estimates on tributaries of importance for the Local Actions Program, simulate results for the full ensemble of General Circulation Models[2] (GCMs) that are now available, and re-evaluate the analysis of projected changes in peak flows. Climate change analyses would be conducted in the near and long term for the entire Chehalis Basin including the mainstem and tributaries.

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[1] The basin-wide hydrologic model uses the Distributed Hydrologic Soil Vegetation Model (DHSVM) software. DHSVM simulated rainfall-runoff processes and can be used to evaluate the effects of natural and human-induced changes on hydrology.

[2] Climate models, also known as general circulation models or GCMs, use mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere, and land.

Near-term Options

The following option could be completed in the next few months:

- Apply a climate change factor of 26% for peak flows to the Local Actions Program. This factor was also used in the SEPA Draft EIS and Aquatic Species Restoration Plan (ASRP) analysis. This would allow direct comparisons with previous work.

An optional addition would be to adjust this change factor based on the potential range in climate projections (e.g., by 50% instead of 26%). Alternative change factor(s) would be selected based on expert judgment and would not involve new modeling. This option would better account for the high end of potential climate changes on flood extents.

Long-term Options

The following long-term options could be implemented over the next several years. All three of these options could be implemented.

- **Option 1.** Use 11 additional GCMs (for a total of 12 GCMs) as input to the DHSVM hydrologic model. Additional GCMs would better represent the range of potential changes in future flows. By using GCMs to evaluate the range, this approach provides a more robust assessment of potential climate change than the expert judgment described previously. Fewer GCMs could be implemented if time and budget are limited.
- **Option 2.** Improve the calibration of the DHSVM hydrologic model. This could benefit the Local Actions Program by providing more accurate flow estimates on the major tributaries, although one cannot know a priori how much the model calibration will be improved.
- **Option 3.** Re-evaluate the peak flow statistics based on the results of Options 1 or 2, or both. The advantage of this option is that it could provide change estimates that are specific to each tributary while also improving the overall understanding of the effects of climate change on flows.

Questions for the Technical Advisory Group

Specific questions for the Technical Advisory Group to consider:

1. What questions do you have about the approach used in the SEPA analysis?
2. What are the pros and cons of each option that should be considered by the Chehalis Basin Board?
3. Are there other options that should be considered for the near or long term?
4. What option would you recommend the Board consider implementing in the short and long term?

Methodologies and Assumptions

For the SEPA Draft EIS, climate change modeling used available climate change data provided by CIG (Ecology 2020). These climate change predictions were also factored into the habitat modeling analysis for the ASRP. A description of the methodologies and assumptions, as described in memoranda developed for the Chehalis Basin Strategy, is provided in Appendix A.

In summary, average peak flows were predicted to increase by 13% at mid-century and 11% by late-century for the low-end emissions scenario. Average peak flows were predicted to increase by 11% at mid-century and 26% by late-century for the high-end emissions scenario. Predicted changes in storm flow volumes showed similar results to the peak flow analysis. The use of dynamically downscaled GCM projections is more refined than previous climate change analyses completed for the Programmatic SEPA EIS. However, the major limitation of the analysis was the lack of enough GCM input datasets to reliably estimate the potential range of future conditions because only two dynamically downscaled GCM projections—ACCESS 1.0 RCP 4.5 (low-end emissions scenario) and GFDL CM3 RCP 8.5 (high-end emissions scenario)—were available at the time of the study.

It was discovered later that an error was made in the development of the GFDL CM3 RCP 8.5 GCM projection. The updated model results showed an average peak flow increase for late-century conditions for the GFDL CM3 RCP 8.5 simulation of 50% (compared to 26%). The results for mid-century conditions were consistent with the previous results. Because the model predictions used in the SEPA Draft EIS are in the middle of the range of RCP 8.5 models, it was determined that the assumptions generated were still reasonable and the determinations of probable significant impact would remain unchanged with the updated climate change predictions.

CIG Comment Letter on SEPA Draft EIS (May 2020)

CIG submitted a comment letter for the SEPA Draft EIS (CIG 2020) providing feedback on the scientific approach used for climate change predictions. CIG commended Ecology for including climate change analyses for and integrating climate change throughout the assessment. CIG also had comments and recommendations for improvements on climate change analyses completed in the SEPA Draft EIS. CIG's comments and recommendations focused on two areas, described as follows:

1. **Use multiple climate change projections.** CIG's main comment noted the limited consideration of potential future conditions in the SEPA Draft EIS climate change analysis. CIG recommended that the climate change analysis should analyze potential effects of multiple projections and then identify and analyze climate change projections that produce the largest negative impacts. As noted in previous sections, the climate change projection used in the SEPA Draft EIS was found to be a mid-range projection. CIG recognized that the data available at the time of analyses were limited, so it was understandable that a range of projections or a high-end projection was not included. With new information now available, CIG recommended that a sensitivity analysis be

completed to analyze if conclusions in the SEPA Draft EIS would be different if the climate change analyses were replaced with a high-end scenario (see Appendix A).

2. **Standardize climate change projections across analyses.** Another comment on the SEPA Draft EIS from CIG noted that modeling of Chehalis River temperature was based on projections that were different than projections used in the analyses from the *Chehalis River Basin Hydrologic Modeling Memorandum* (WSE 2019). These two projections had different time periods and used different GCMs. CIG noted that the GCM differences are likely most important—water temperatures would likely show higher warming. CIG recommended that the stream temperature modeling be updated to include projections from the 2019 GCMs. Alternatively, CIG notes that stream temperature projections could be scaled based on the difference between the old and new air temperature projections.

NSD Comment Letter on SEPA Draft EIS (April 2020)

NSD prepared a comment letter for the SEPA Draft EIS (NSD 2020), which was submitted by the Quinault Indian Nation. A section of the letter provided comments on the climate change modeling. As in CIG's comment letter, the NSD comments noted that the modeling team did not use the ensemble approach, in which multiple GCMs are used to characterize the uncertainty associated with the projections.

Options for Analyses

At the request of OCB, CIG, Watershed Science and Engineering (WSE), and Anchor QEA identified the following options for climate change assumptions that could be incorporated into future hydrologic and hydraulic modeling for a Local Actions Program in both the near- and long-term time frames.

Options for Near-term Analyses

At a minimum, the same scalars used for the SEPA Draft EIS and ASRP analyses could be used for late-century (26% increase in peak flow) in identifying the extent of the future floodplain and analyzing Local Actions Program projects. As described previously in this memorandum, this is in the middle of the range among model projections for the high-end RCP 8.5 greenhouse gas scenario and allows for an apples-to-apples comparison with the modeling for the SEPA Draft EIS and ASRP. No additional climate change modeling or analysis would be required. This option would not evaluate the potential full range of climate change conditions, as would be done in an ensemble approach where multiple GCMs are used to characterize the uncertainty associated with the projections.

As mentioned previously, corrected analysis from CIG since the SEPA Draft EIS was produced indicates that larger changes in precipitation and peak flows are possible. The implications of flow changes greater than 26% could also be evaluated. Because there is not sufficient time to run additional hydrologic model simulations in the near-term, scaled up peak flows could be used as input to the hydraulic modeling (e.g., by 50% instead of 26%). This scalar could be developed either by professional judgment (by CIG) or using the analysis performed in December 2019 to evaluate the corrected GFDL simulations (which can be assumed to represent a high-end climate change scenario). Although there is not enough time to directly incorporate new regional climate model projections, by scaling the peak flows with the higher scalar, the potential effects of a larger change in flows could be evaluated as part of the near-term analyses for the Local Actions Program.

Options for Long-term Analyses

Option 1: Explore range in climate projections by evaluating additional GCM projections in existing DHSVM model

For this option, downscaled meteorological inputs would be prepared for the full ensemble of 12 GCMs now available from CIG. This directly addresses the issues raised by CIG and NSD in their SEPA Draft EIS public comment letters by including a sufficiently large number of GCMs to characterize the range among projections. The preferred option is to use all 12 GCM projections; research suggests that at least 6 to 10 models are needed to accurately represent the range among projections. Although not the preferred option, this could be reduced to three GCMs if time and budget are limited, by selecting models that represent the high-end, low-end, and middle of the range.

To implement this option, the following steps would need to occur:

- Develop DHSVM inputs for each GCM.
- Run DHSVM for the period of record (1970 to 2099) using the new GCM inputs.
- Post-process the DHSVM output as done previously for the GFDL and ACCESS GCMs and determine appropriate scalars for use in developing late-century hydrologic inputs.

This option could be implemented independent of the other options.

Option 2: Improve DHSVM model accuracy and calibration

For this option, the input to the DHSVM hydrologic model would be revised to correct biases in the spatial distribution of precipitation, which were suspected to be present based on post-model evaluations. Once the model is recalibrated, all climate change simulations would need to be repeated. The principal advantage of this option is the potential to improve the model's representation of peak flows, especially on tributaries that may be important for the Local Actions Program. The primary disadvantage of this option is that one cannot know a priori how much the model performance will be improved.

To implement this option, the following steps would need to occur:

- Devise corrections to meteorological inputs.
- Calibrate DHSVM hydrologic model.
- Run DHSVM for the period of record (1970 to 2099) for all GCM inputs.
- Post-process the DHSVM output for all simulations and determine appropriate scalars for use in developing late-century hydrologic inputs.

This option could be implemented independent of the other options.

Option 3: Re-evaluate the approach to developing flow scalars

Using new projections — developed in either Options 1 or 2 — re-evaluate the approach to developing flow scalars for the hydraulic model simulations. Specifically, evaluate the following:

1. If the spatial pattern of projected changes follows a consistent pattern;
2. If the projected changes for each quantile (i.e., 2-year, 10-year, 100-year) follow a consistent pattern; and
3. If the uncertainty in the extreme statistics can be improved by using a "bootstrapping" approach.

Based on this analysis, OCB's technical consultants would provide a recommendation for how to scale existing hydrologic data by quantile and/or basin/region to reflect potential climate change effects. This option would improve the estimates of peak flows by geographic area, which could be used in analyses of Local Actions Program projects in subbasins and smaller urban areas.

This option should be implemented in tandem with either Option 1, Option 2, or both. Although it could be implemented independently, the advantages of doing so would be limited.

References

CIG (Climate Impacts Group), 2020. Letter to: Washington State Department of Ecology. Regarding: Comments on Chehalis Basin SEPA DEIS. May 23, 2020.

Ecology (Washington Department of Ecology), 2020. *SEPA Draft Environmental Impact Statement Publication No. 20-06-002 for the Proposed Chehalis River Basin Flood Damage Reduction Project*. February 2020.

NSD (Natural Systems Design), 2020. Memorandum to: Quinault Indian Nation. Regarding: Critical Review of Proposed Chehalis River Basin Flood Damage Reduction Project SEPA DEIS Hydrology Technical Memo 2: Hydrology and Climate Change Technical Analyses Review. April 22, 2020.

WSE (Watershed Science and Engineering), 2019. Memorandum to: Bob Montgomery, Anchor QEA. Regarding: Chehalis River Basin Hydrologic Modeling. February 28, 2019.

APPENDIX A
METHODOLOGIES AND ASSUMPTIONS

Chehalis River Basin Hydrologic Modeling Memorandum (February 2019)

The *Chehalis River Basin Hydrologic Modeling Memorandum* (WSE 2019) summarized work performed to develop and calibrate a hydrologic model of the Chehalis Basin extending from the headwaters of the Chehalis River upstream of Pe Ell to the mouth of the river at Grays Harbor, including all tributaries to the Chehalis River and Grays Harbor. Modeling was performed using the DHSVM model. Meteorological data were provided by CIG and included a historical dataset from January 1981 to December 2015 and two long-term historical/future datasets based on GCM simulations from 1970 to 2099.

The modeling study was the first time that dynamically downscaled meteorological data (i.e., based on regional climate model simulations) were used to both develop climate change projections and calibrate a basin-wide hydrologic model of the Chehalis Basin. Previous meteorological datasets were based on statistically downscaled projections, which studies show do not provide accurate projections of changing flood conditions (Salathé et al. 2014). Previous studies also only used daily values, whereas the new CIG datasets provide hourly data. The DHSVM model was calibrated and verified by comparing simulated flows against observed data and peak annual flow data from five U.S. Geological Survey stream gaging stations in the basin. Once calibrated, the DHSVM model was run using the long-term meteorological datasets to evaluate potential climate change impacts on Chehalis River basin hydrology.

Model results for the Chehalis Basin varied depending on location. The results showed that basin hydrology is simulated reasonably well against the historical record and there does not appear to be an overall trend regarding overestimation or underestimation of peak flows or runoff volumes. However, some locations and recurrence intervals are poorly replicated by the model and the most extreme floods are difficult to calibrate well.

For climate change simulations, two long-term GCM datasets—ACCESS 1.0 RCP 4.5 (low-end emissions scenario) and GFDL CM3 RCP 8.5 (high-end emissions scenario)—were run for the full period of meteorological record (1970 to 2099). Peak annual flows from simulated hourly flow data were divided into three 45-year periods: 1970 to 2015 (current), 2016 to 2060 (mid-century), and 2055 to 2099 (late-century). Frequency analyses were developed, and current flow frequencies were compared to mid-century and late-century flow frequencies. It was found that average peak flows were predicted to increase by 13% at mid-century and 11% by late-century for the low-end emissions scenario. Average peak flows were predicted to increase by 11% at mid-century and 26% by late-century for the high-end emissions scenario. Predicted changes in storm flow volumes showed similar results to the peak flow analysis.

Because the historical GCM data simulated with DHSVM did not match observed conditions particularly well, it was recommended to not use the actual simulated flows as input for other models. Instead, it was recommended that flow hydrographs previously developed to represent current conditions continue to be used for historical flow simulations but be scaled up to represent future conditions until improved meteorological data or model refinement could be completed. Relative flow changes (by percentage) between current conditions and future conditions were calculated and applied to current conditions flows. Although the use of dynamically downscaled GCM projections is more refined than previous analyses, the major limitation of the analysis was the lack of enough GCM input datasets to reliably estimate the potential range of future conditions because only two dynamically downscaled GCM projections were available at the time of the study. It was also discovered later in 2019 that an error was made in the development of the GFDL CM3 RCP 8.5 GCM projection, which is addressed in the December 2019 *Climate Change Projections and Draft SEPA EIS Documentation Memorandum* described in the following section.

Climate Change Projections and Draft SEPA EIS Documentation Memorandum (December 2019)

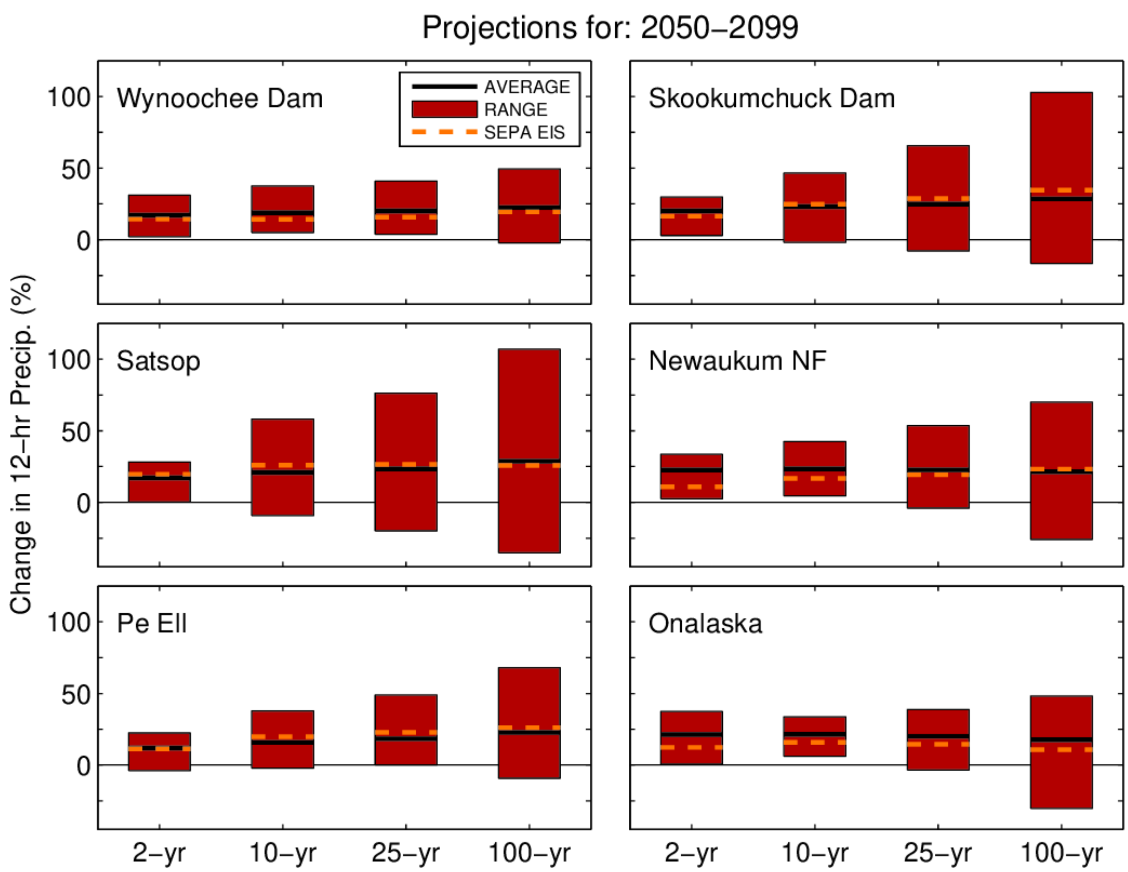
The *Climate Change Projections and Draft SEPA EIS Documentation Memorandum* (Anchor QEA and ESA 2019) was prepared to summarize climate change projection data corrected and updated by CIG as described in an October 2019 memorandum (CIG 2019) and further analyzed by WSE. The corrected and updated climate change projections provided by CIG address a technical error in the GFDL CM3 RCP 8.5 GCM simulations. WSE used these corrected data to recompute peak flow changes at 15 gages in the Chehalis Basin and compare these against newly available climate data from 11 other GCMs.

According to the *Climate Change Projections and Draft SEPA EIS Documentation Memorandum*, the corrected and updated meteorological data were input to the DHSVM hydrologic model and a change in peak flow was calculated using the same technique as described in the *Chehalis River Basin Hydrologic Modeling Memorandum*. The updated model results showed an average peak flow increase for late-century conditions for the GFDL CM3 RCP 8.5 simulation of 50% (compared to 26% in the *Chehalis River Basin Hydrologic Modeling Memorandum*, obtained from the older erroneous GFDL CM3 RCP 8.5 simulation). The results for mid-century conditions were consistent with the previous results. The ACCESS 1.0 RCP 4.5 simulation did not require re-running the hydrologic model.

Also as noted in the *Climate Change Projections and Draft SEPA EIS Documentation Memorandum*, additional RCP 8.5 (high emissions scenario), GCMs were not available at the time of the analyses completed for the *Chehalis River Basin Hydrologic Modeling Memorandum.* Projections of precipitation from the other RCP 8.5 GCM models were compared to both the old and new GFDL CM3 model projections; the revised (new) GFDL CM3 model projections appeared to be on the higher end when compared to other RCP 8.5 models. However, the old GFDL CM3 model projections—based on the erroneous simulation, used in the February 2019 results—appeared to be a mid-range projection for late-century conditions, among the RCP 8.5 models.

Because the model predictions in the SEPA Draft EIS are in the middle of the range of RCP 8.5 models, it was determined that the assumptions generated were still reasonable and the determinations of probable significant impact would remain unchanged with the updated climate change predictions.

Figure A-1
Projected Change in 12-hour Precipitation Statistics for 2050 to 2099 Relative to 1970 to 2015, for Six Sites Spanning the Chehalis Basin



The bars show the range of projections among the full ensemble of 12 GCM projections; the black line shows the average change for all 12 models. The dashed orange line shows the precipitation change used in the *Chehalis River Basin Hydrologic Modeling Memorandum* (WSE 2019).

The above conclusions are based on the projected changes in precipitation, which may be different from the resulting changes in streamflow. Although heavy precipitation is the primary driver of flooding in the Chehalis Basin, peak flows could be affected by antecedent conditions and the spatial distribution of precipitation as well as its intensity. To understand the implications for streamflow, one would need to run the hydrologic model using additional GCM simulations as input.

Appendix A References

Anchor QEA and ESA (Anchor QEA, LLC, and Environmental Science Associates), 2019. Memorandum to: Diane Butorac, Washington Department of Ecology. Regarding: Climate Change Projections and Draft SEPA EIS Documentation. December 8, 2019.

CIG (Climate Impacts Group), 2019. Memorandum by: Guillaume Mauger, Climate Impacts Group, University of Washington. Regarding: Differences Between the Old and New GFDL CM3 Projections. October 30, 2019.

Salathé, E.P., A.F. Hamlet, C.F. Mass, S.Y. Lee, M. Stumbaugh, and R. Steed, 2014. "Estimates of Twenty-First-Century Flood Risk in the Pacific Northwest Based on Regional Climate Model Simulations." *Journal of Hydrometeorology* 15:1881-1899.

WSE (Watershed Science and Engineering), 2019. Memorandum to: Bob Montgomery, Anchor QEA. Regarding: Chehalis River Basin Hydrologic Modeling. February 28, 2019.