

**Appendix C**  
**Earthquake Catalog**



## Appendix C

### Earthquake Catalog

This appendix describes the uniform moment magnitude catalogs of crustal and subduction earthquakes, and the databases of earthquakes that were assembled as part of the Hanford Probabilistic Seismic Hazard Analysis (PSHA) project to obtain these catalogs. Section C.4 describes the database of earthquakes used to derive the magnitude conversion relations used to obtain a uniform moment magnitude. The methodology and the analyses are described in Chapter 6.0 of this report.

#### C.1 Uniform Moment Magnitude Catalog of Crustal Earthquakes

The earthquake catalog of crustal seismicity is the basis for obtaining earthquake recurrence parameters for the background source zones, and it is also used in the assessment of the maximum magnitude ( $M_{max}$ ) and focal depth distributions. As discussed in Chapter 6.0, for each earthquake the catalog reports the expected moment magnitude ( $M_w$ ) given the uncertainty in its assessment ( $E[M]$ ). The catalog also contains the equivalent earthquake counts ( $N^*$ ), which are to be used in the assessment of earthquake recurrence parameters.

The catalog is available in electronic format in the ASCII file CrustM.cat (included with this appendix as supplemental information). The fields are described below.

EqNo	Sequential identification number assigned to each earthquake.
Year, Month, Day	Earthquake date.
Hour, Minute, Second	Earthquake time in coordinated universal time (UTC). It should be noted that while every effort was made to identify local time, particularly for historical earthquakes, and convert it to UTC, the reported time relies solely on the time (and date) assigned to the earthquake in the original sources. It is possible that for some historical earthquakes the local times are listed instead of the UTC.
Latitude, Longitude	Earthquake location in degrees north (latitude) and degrees east (longitude). The precision of the locations is that of the preferred earthquake record selected. As shown by the high-precision relocation studies, the variability is generally small and will not affect the recurrence calculations because the b-values are calculated for the entire zone, and smoothing of the a-values is obtained with a varying kernel size, which is much larger than the reported location errors.
Depth	Earthquake focal depth in kilometers.

Depth_F	Flag that indicates the type of focal depth. Possible values are as follows:  0: good quality 1: fixed location and depth (corresponds to # symbol in Pacific Northwest Seismic Network [PNSN] catalog) 2: fixed location and depth (corresponds to \$ symbol in PNSN catalog) 3: depth constrained (corresponds to * symbol in PNSN catalog) 4: fixed depth (from catalogs other than PNSN).
E[ <b>M</b> ]	Expected value of moment magnitude.
sig <b>M</b>	Standard error in the expected moment magnitude E[ <b>M</b> ].
N*	Equivalent earthquake count.

The following two columns are repeated for each of the four declustering algorithms (*i* ranges from 1 to 4):

Flag <sub><i>i</i></sub>	Flag to identify mainshock, foreshock, and aftershock within a sequence:  f: foreshock a: aftershock m: mainshock
SeqNo <sub><i>i</i></sub>	Number assigned to the mainshock/aftershock sequence.

## C.2 Uniform Moment Magnitude Catalog of Subduction Earthquakes

The catalog of subduction earthquakes is used to calculate recurrence rates for the intraslab seismicity. As discussed in Chapter 6.0, the catalog lists all the events associated with the Cascadia subduction and does not distinguish between intraslab or interface because the information is insufficient to separate the two types of earthquakes. Chapter 6.0 also describes the criteria used to separate subduction earthquakes from crustal earthquakes based on a comparison of their focal depths with the depth of the top of the Juan de Fuca slab, interpolated from the McCrory et al. (2006) contour lines. Because there are several earthquakes, mostly pre-instrumental and early instrumental, with fixed or unknown focal depths, two subduction earthquake catalogs were created: one in which all earthquakes with unknown or fixed depths are excluded, and one in which they are all included. The two catalogs are available in electronic format in the ASCII files SubdM.cat and SubdM2.cat, respectively (included with this appendix as supplemental information).

Both catalogs report the expected moment magnitude given the uncertainty in its assessment (E[**M**]) and contain the equivalent earthquake counts (N\*). The fields are described below.

EqNo	Sequential identification number assigned to each earthquake.
Year, Month, Day	Earthquake date.

Hour, Minute, Second	Earthquake time in UTC. It should be noted that while every effort was made to identify local time, particularly for historical earthquakes, and convert it to UTC, the reported time relies solely on the time (and date) assigned to the earthquake in the original sources. It is possible that for some historical earthquakes the time local times are listed instead of the UTC.
Latitude, Longitude	Earthquake location.
Depth	Earthquake focal depth in kilometers.
Depth_F	Flag that indicates the type of focal depth. Possible values are as follows:  0: good quality 1: fixed location and depth (corresponds to # symbol in PNSN catalog) 2: fixed location and depth (corresponds to \$ symbol in PNSN catalog) 3: depth constrained (corresponds to * symbol in PNSN catalog) 4: fixed depth (from catalogs other than PNSN) 5: depth assigned by a geophysicist (flag “G” in some catalogs) 6: assigned focal depth, but calculated origin time (corresponds to “H” in the Seismic Hazard Earthquake Epicenter File [SHEEF] catalog).
E[ <b>M</b> ]	Expected value of moment magnitude.
sig <b>M</b>	Standard error in the expected moment magnitude E[ <b>M</b> ].
N*	Equivalent earthquake count.

The following two columns are repeated for each of the four declustering algorithms (*i* ranges from 1 to 4):

Flag <sub><i>i</i></sub>	Flag to identify mainshock, foreshock, and aftershock within a sequence:  f: foreshock a: aftershock m: mainshock
SeqNo <sub><i>i</i></sub>	Number assigned to the earthquake sequence.

### C.3 Earthquake Catalog Databases

The earthquake catalogs described in Sections C.1 and C.2 are the final results of an extensive compilation effort in which earthquake records from various catalogs and networks were merged. A

complete list of all the earthquake records collected and analyzed to produce the crustal and subduction catalogs for the Hanford PSHA project is saved in two files: `Crustal_mastercatalog_rev0.xlsx` and `Subd_mastercatalog_rev0.xlsx`.

### C.3.1 Crustal Earthquake Catalog Database

The crustal earthquake catalog database contains all the earthquake records collected in the geographic region between latitude 45° north and 49° north and longitude -121.5° east and -117.5° east and earthquakes that are not associated with the slab. These include non-tectonic events and often multiple duplicates. The file `Crustal_mastercatalog_rev0.xlsx` is organized using two tabs. Under the first tab (“Hanford\_multiple\_records”), the records are color-coded based on the catalog from which they were retrieved. For instance, records from the Advanced National Seismic System (ANSS) are blue and records from PNSN are magenta. Once the preferred record is selected, it is placed before all of its duplicates, assigned a unique earthquake number (sequential), and the color is changed to black. Under the second tab (“Hanford\_single\_record\_tect”) are only the preferred record for each earthquake, and not the earthquakes flagged as non-tectonic.

A description of the information contained in each column of the database is provided below.

SortID	Unique identification number assigned to each record and used to maintain the database sorting.
EqNo	Unique identification number assigned only to the preferred record of each earthquake.
RecordID	Label and sequential number that identifies the record and connects it to the source catalog. Acronyms used are listed in Table C.3.1-1 (at the end of this appendix).
Year, Month, Day	Earthquake date.
Hour, Minute, Second	Time of the event. When necessary the time has been converted from local to UTC in the preferred record; the duplicate records maintain the original time as it appears in the source catalogs. A comment is used to keep track of the change.
Lat, Long	Epicentral coordinates; latitude is in degrees north, longitude in degrees east.
Depth	Focal depth in kilometers from the ground surface.
Depth1_Flag	Symbols and letters that are used to indicate if the depth is fixed: #: fixed location and depth (PNSN catalog) \$: fixed location and depth (PNSN catalog) *: depth constrained (PNSN catalog) F: fixed depth (catalogs other than PNSN) G: depth assigned by a geophysicist (catalogs other than PNSN)
Mi	$i^{\text{th}}$ magnitude value (i ranging from 1 to 12).
Mi_typ	type of the $i^{\text{th}}$ magnitude (i ranging from 1 to 12).
Mi_src	Source of the $i^{\text{th}}$ magnitude (i ranging from 1 to 12). Acronyms used are listed in Table C.3.1-2.
Moi	$i^{\text{th}}$ seismic moment (i ranging from 1 to 2).

Source_Moi	Source of the $i^{\text{th}}$ seismic moment (i ranging from 1 to 2).
MMI1	Modified Mercalli Intensity at the epicenter.
MMI1_Src	Source of the Modified Mercalli Intensity. Acronyms used are listed in Table C.3.1-2.
I0_2	Additional macroseismic intensity at the epicenter.
I0_2_TYPE	Type of macroseismic intensity.
I02_Src	Source of the additional macroseismic intensity. Acronyms used are listed in Table C.3.1-2.
LNFA (km <sup>2</sup> )	Natural log of the felt area in square kilometers.
LNFA_Src	Source of the natural log of the felt area. Acronyms used are listed in Table C.3.1-2.
ERH	Horizontal error (currently not listed).
ERH_src	Source of the horizontal error (currently not listed).
Aftershock	Flag to mark records identified as fore- or after-shock in the original catalogs.
Source	Source of the record. Acronyms used are listed in Table C.3.1-2
NonTect	Flag to identify non-tectonic events:  F: false event V: volcanic origin X: explosion PF: probably false PV: probably volcanic
Nontect_SRC	Source that identifies the non-tectonic event. Acronyms used are listed in Table C.3.1-2.
Comment	Notes and comments.

### C.3.2 Subduction Earthquake Catalog Database

The subduction earthquake catalog database contains all the earthquake records collected, including crustal earthquakes and often duplicate records. The file Subd\_mastercatalog\_rev0.xlsx is organized in four tabs. In the first tab (“merge\_records”) the records are color-coded based on the catalog from which they are retrieved: records from the ANSS are in red; records from the SHEEF are in blue, and records from the PNSN are in black. Column W (“JDF depth”) contains the depth to the top of the Juan de Fuca slab calculated by interpolation of the McCrory et al. (2006) contour lines at the epicentral location; column X (“Subduction”) contains a label that identifies which earthquakes are crustal and which are subduction or unresolved. Column Y (“Remove”) contains a flag that is used to remove earthquakes associated with the Blanco Ridge or other offshore areas that are not of interest for this project.

The second tab (“Subd\_flag\_duplicates”) contains only events labeled as “subduction” and includes a flag (Column Y) to identify the duplicate entries that are to be removed. Details about the selection of the preferred record are given in Chapter 6.0. The third tab (“Subduction\_final”) contains only the preferred earthquake records and is used to obtain catalog SubdM.cat (after converting magnitudes to  $E[M]$ ). The

last tab (“doubtful”) lists the earthquakes with unknown or fixed depth. These earthquakes are added to the catalog in tab “Subduction\_final” to generate the second subduction catalog, SubdM2.cat.

A description of the information contained in each column of the database is provided below.

SortID	Unique identification number assigned to each record and used to maintain the database sorting.
RecordID	Label and sequential number that identifies the record and connects it to the source catalog. Acronyms used are listed in Table C.3.2-1 (at the end of this appendix).
Year, Month, Day	Earthquake date.
Hour, Minute, Second	Time of the event. When necessary the time has been converted from local to UTC in the preferred record; the duplicate records maintain the original time as it appears in the source catalogs. A comment is used to keep track of the change.
Lat, Long	Epicentral coordinates; latitude is in degrees north, longitude in degrees east.
Depth	Focal depth in kilometers.
Depth1_Flag	Symbols and letters that are used to indicate if the depth is fixed: #: fixed location and depth (PNSN catalog) \$: fixed location and depth (PNSN catalog) *: depth constrained (PNSN catalog) F: fixed depth (catalogs other than PNSN) G: depth assigned by a geophysicist (catalogs other than PNSN) H: assigned focal depth, but calculated origin time (SHEEF catalog).
Mi	$i^{\text{th}}$ magnitude value (i ranging from 1 to 3).
Mi_typ	type of the $i^{\text{th}}$ magnitude (i ranging from 1 to 3).
<b>M</b>	Moment magnitude (typically from the Harvard catalog).
SigM	Standard error of the moment magnitude calculated from Harvard data.
Mo	Seismic moment (from Harvard catalog).
Numsta, Numphase, Gap, MinD, RMS, Err, Q1,Q2, VelMod	Parameters of the solution (from PNSN).
JDF depth	Depth of the top of the slab from interpolation of McCrory et al. (2006) contour lines.
Selection	Label identifying earthquakes associated with the subduction (either Subduction, Crustal, or ?).
Location	Label indicating the general area where the earthquake is located (only available for a few historical earthquakes).
I0	Macroseismic intensity at the epicenter.
I0 Type	Scale on which $I_0$ is measured.
Felt Area	Area over which the earthquake was felt.
Felt Area type	Unit measure of the felt area.

## C.4 Data Set Used to Obtain the Magnitude Conversion Relations

The data set used to derive the magnitude conversion relations is saved in file MagConvDB\_rev0.xlsx. The data are saved in separate tabs called “M<sub>x</sub>-M” where M<sub>x</sub> is the size measure (magnitude or intensity) that is being converted to M; two additional tabs called “ML-MD crustal” and “ML-MD subduction” contain the data used to convert ML to MD.

A description of the information contained in each column of the database is provided below.

EqNo	Unique identification number assigned to each earthquake (duplicate records have the same EqNo).
Year, Month, Day	Earthquake date.
Hour, Minute, Second	Origin time of the event. When necessary the time has been converted from local to UTC in the preferred record; the duplicate records maintain the original time as it appears in the source catalogs. A comment is used to keep track of the change.
Lat, Long	Epicentral coordinates; latitude is in degrees north, longitude in degrees east.
Depth	Focal depth in kilometers.
	In tabs “mb-M”, “Ms-M”, “MD-M” and “ML-M”:
<b>M1</b>	Moment magnitude estimate (1 of 2).
Mo	Seismic moment.
<b>M2</b>	Alternative moment magnitude estimate (if available).
SigEq	Standard error of the observed moment magnitude (see discussion in Chapter 6.0).
<b>M2</b>	Alternative moment magnitude estimate (if available).
<b>M</b>	Moment magnitude calculated combining the available estimates (see discussion in Chapter 6.0).
sig <b>M</b>	Standard error of the expected moment magnitude.

For mb and Ms only:

xx_type	Type of mb or Ms (xx is mb or Ms)
	In tabs “mb-M”, “Ms-M”, “MD-M”, “ML-M”, “ML-MD Crustal” and “ML-MD Subduction”:
xx	Observed magnitude value (xx can be mb, Ms, MD, ML).
xx_source	Agency or catalog reporting the observed magnitude (xx can be mb, Ms, MD, ML).
weight	Weight assigned to each magnitude value.
Type	Type of earthquake; can be either crustal or subduction.

In tab “I0-M”, after the depth column there are columns with the observed **M**, Ms, MD, each followed by a column indicating the source catalog or agency; then three columns contain respectively the expected **M** (E[**M**]) from observed **M**, Ms, and MD, the macroseismic intensity and the agency or catalog reporting the intensity. The last column contains the weight assigned to each record.

## C.5 Acronym Tables

**Table C.5.1-1.** Acronyms used in the RecordID field.

Acronym	Explanation
ANSS	Advanced National Seismic System
CHE	Mid-Columbia Project data for 2006-2008
HAN	Hanford Network
HIST	Historical Earthquake Catalog of Eastern Washington (Rohay 1989)
ISC	International Seismological Center
NEDB	National Earthquake Data Base (Canada)
NEIC	National Earthquake Information Center (U.S.)
ORWA	Mid-Columbia Project data up to 2006
PNSN	Pacific Northwest Seismic Network
ODOT	Oregon Department of Transportation (Geomatrix 1995)

**Table C.5.1-2.** Acronyms used in the earthquake catalog database.

Acronym	Explanation
ANF	USArray Array Network Facility
ANSS	Advanced National Seismic System
Bakun	Bakun et al. (2002)
BUT	Montana Bureau of Mines and Geology
BYERL	Byerly (1952)
CascHist	Cascadia Historical Earthquake Catalog
CGS	Coast and Geodetic Survey of the United States
DNAG1	Decade of North American Geology
DYFI	Did You Feel It?
EIDC	Experimental (GSETT3) International Data Center
GCR	Rogers (1983)
GS	U.S. Geological Survey
GSC	Geological Survey of Canada
GUTE	Gutenberg and Richter (1949)
HANFORD	Hanford Network
Holden	Holden (1898)
IDC	International Data Center (CTBTO)
ISC	International Seismological Center
ISCJB	International Seismological Center Jeffreys-Bullen tables
ISS	International Seismological Summary
LAO	Large Aperture Seismic Array
LON	Longmire, Washington (SEA station)
Lud	1997 Ludwin Catalog as referred to in URS (2007)
LUDWIN	1997 Ludwin Catalog as referred to in URS (2007)
Ludwin2	Ludwin Catalog , 2nd edition (Ludwin 2006)

**Table C.5.1-2 (contd)**

Acronym	Explanation
MOS	Geophysical Survey of Russian Academy of Sciences
MWR	Monthly Weather Review
NAO	Stiftelsen NORSAR
NEI	National Earthquake Information Center
NEIC	National Earthquake Information Center
NEIS	National Earthquake Information Center
NGDC	National Geophysical Data Center
NOA	National Oceanic and Atmospheric Administration
ORWA	Mid-Columbia catalog
OTT	Canadian Hazards Information Service, Natural Resources Canada
PAS	Caltech
pde	Preliminary Determination of Epicentres
PDE1	Preliminary Determination of Epicentres
PGC	Pacific Geoscience Centre
PNNL	Pacific Northwest National Lab
PNSN	Pacific Northwest Seismic Network
RAS	Rasmussen (1967)
REID	Unpublished notes of Henry Fielding Reid
SEA	University of Washington - Seattle
SLM	Saint Louis University
StoCof	Stover and Coffman (1993)
TAWA	Townley and Allen (1939)
TERR	Terranova, Guatemala (GCG station)?
Unk	Unknown
USCGS	Coast and Geodetic Survey of the United States
USEQS	U.S. Department of Commerce (1973)
USGS	U.S. Geological Survey
UVWAS	University of Washington
UVWASH	University of Washington
UvWash1	University of Washington
UW	University of Washington
W&C	Woodward-Clyde Consultants
WCC	Woodward-Clyde Consultants
WCFS	Woodward-Clyde Federal Services
WPPSS	Washington Public Power Supply System
ZOLL1994	University of Washington catalog 1962-1994
ZOLLWG	University of Washington catalog 1962-1994
CTBTO = Control of the Test Ban Treaty Organization	

**Table C.5.2-1.** Acronyms used in the RecordID field.

Acronym	Explanation
ANSS	Advance National Seismic System
PNSN	Pacific Northwest Seismic Network
SHEEF	Seismic Hazard Earthquake Epicenter File (Geological Survey of Canada)

## C.6 References

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