WAV Format Preservation Assessment

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British Library Digital Preservation Team
digitalpreservation@bl.uk

1. Introduction

This document provides a high level, non-collection specific assessment of the Waveform Audio File Format (WAV, WAVE) with regard to preservation risks and the practicalities of preserving data in this format.

This format assessment is one of a series of assessments carried out by the British Library's Digital Preservation Team.

1.1 Scope

This document focuses on the Waveform Audio File Format (WAV, WAVE) as well as variant extensions such as Broadcast WAVE (BWF) and the RF64 formats.

Note that this assessment considers format issues only, and does not explore other factors essential to a preservation planning exercise, such as collection specific characteristics of collections. These should always be considered before implementing preservation actions.

1.2 Summary

The Waveform Audio File Format, often referred to as WAV or WAVE, is an audio file format standard for storing an audio bitstream. It is built upon the Resource Interchange File Format (RIFF) wrapper format and stores data in chunks, each chunk consisting of data plus identifier and length. WAV is typically used to store uncompressed audio, e.g. in the linear pulse code modulation (LPCM) format. Uncompressed content mean that the files are often very large, but there is a size limitation of 4GB of audio data per data chunk [1]. The format was originally developed by Microsoft and IBM in 1991, and is compatible with most of the most widely used operating systems, including Windows, Macintosh and Linux [1].

The popularity of WAV has much to do with its familiarity with audio professionals and its relatively simple structure [1]. The format can be used to encode both born-digital audio, e.g. with several musical recording packages allowing the creation of WAV files [2] [3] [4], as well as being a target format for digitisation activities.

WAV has been a de facto standard for over 20 years in the music, audio and broadcasting industries and there are no current reported plans for the format to be revised. According to Wikipedia, it is viewed as "suitable for retaining first generation archived files of high quality, for use on a system where disk space is not a constraint, or in applications such as audio editing, where the time involved in compressing and uncompressing data is a concern" [1].

2. Assessment

2.1 Development Status

A summary of the development history of the format and an indication of its current status

The WAV format was originally developed in 1991 by Microsoft and IBM for use with Windows 3.1. It is an instance of the Resource Interchange File Format (RIFF) and uses its "chunk"-based, tagged file structure. RIFF files are made up of one or more chunks, each identified by a four-character code. WAV itself is a wrapper that can incorporate audio bitsteams and other data chunks. The audio in a WAV file can be compressed, but the format is used most often for uncompressed audio, e.g. encoded in LPCM (Linear Pulse Code Modulation).

There are a number of modifications of the WAV format.

Broadcast Wave Format (BWF) is an extension of WAV audio format which has an additional Broadcast Audio Extension chunk for the metadata required for broadcast applications. Consequently, it is the recording format standard used most for film, radio and TV productions. Version 1 [5] was first specified by the European Broadcasting Union (EBU) in 1997, and subsequently updated in 2001 [6] and 2003 [7], becoming a de facto standard in the audio and broadcasting world. Version 2 of BWF was published in 2011 [8], although the most significant change was the inclusion of metadata relating to the measurement of loudness [5].

BWF retains the same file size limitations as WAV files (4GB) which is enforced by the file size header [1]. An EBU-developed extension to BWF, RF64 (also known as MBWF) [9], enables file sizes to exceed 4GB [7], although this is not strictly-speaking RIFF-compliant.

The Audio Interchange File Format (AIFF) was released in 1988 and is Apple's proprietary version of WAV for Macintosh computers [10] and is based on the same Interchange File Format from which RIFF was developed. It is not interoperable with WAV (though it can be converted) and has its own file extension, .aiff. Differences between the formats include their support for steaming (in AIFF streaming depends upon the ordering of chunks, while WAV requires rendering information to precede sample data) and their treatment of multi-channel audio (which is incomplete in WAV and ambiguous in AIFF) [11].

In recent years, other lossless formats such as FLAC have become more prevalent and should be considered as a serious alternative to WAV as it offers the same levels of quality but with a smaller file size [12].

2.2 Adoption and Usage

An impression of how widely used the file format is, with reference to use in other memory organisations and their practical experiences of working with the format

Several professional organisations have specifically recommended the use of WAVE or BWF files for the long-term preservation of sound files, especially in the context of digitisation.

For example, the very influential International Association of Sound and Audiovisual Archives (IASA) TC-04 *Guidelines on the Production and Preservation of Digital Audio Objects* [13] recommends the use of WAVE as an archival format. This is partly based on "the simplicity and ubiquity of linear Pulse Code Modulation," but the guidelines also note that the widespread use of the format by the professional audio industry meant that there would be a greater probability "of professional tools being developed to migrate the format to future file formats when that becomes necessary" (Section 2.8.1). The IASA guidelines additionally recommend the use of BWF .wav files (i.e., EBU Tech 3285), which would enable the better handing of metadata, and which are also judged to be "widely accepted by the archiving community" (Section 2.8.2).

The Association for Recorded Sound Collections (ARSC) Technical Committee's *Recommendations for Preserving Sound Recordings* [14] endorses the IASA TC-04 Guidelines and bases its own work on the general principles elaborated by IASA. The ARSC Recommendations conclude that archival masters should be based upon a "widely available uncompressed format." They note that WAV and BWF act as *de facto* standards for this, although the ARSC Technical Committee argue that BWF is the better choice, "because it provides a specific, defined location within the file itself for metadata about the content, ownership, source recording, and digitizing signal chain associated with the digital file, as well as a unique source identifier (USID)" (p. 5). In addition, the ARSC make recommendations on both bit depth and sample rate, proposing 24 bits per channel for bit depth and a 96 kHz standard sample rate. A more recent *ARSC Guide to Audio Preservation* [15] has also recommended 24-bit, 96-kHz BWF as "the current preferred format for master files" (p. 33).

The Digital Preservation Coalition's Technology Watch Report on *Preserving Moving Pictures and Sound* [16] concludes that the ideal preservation format would be uncompressed and based on a widely-supported open standard, following the IASA guidelines in recommending 24-bit, 48 kHz (at least) BWF, noting that that BWF is widely used and well supported. WAV is also recommended for the preservation of digital audio by the Audio Engineering Society (AES) and the National Academy of Recording Arts and Sciences [17]. In addition, the Library of Congress considers WAV files to be one of their preferred audio formats [18].

Given its high-profile in format recommendations for audio, it is perhaps unsurprising that WAV and BWF are the two most common formats used for the digital preservation of audio [19]. Preservation guidance from the Florida Virtual Campus' Florida Voices initiative suggests that the WAV format "is the most universally accepted file format for digital audio master files" in the US [20]. The format is used by a number of custodial organisations; some examples follow:

- The British Library follows the IASA guidelines for the digitisation of audio [21] and the RF64 header is implemented during digitisation if the total file size exceeds 2GB. As well as digitising using WAV, the British Library also asks for and receives an increasing amount of born digital content in WAV format where it exists for published (and unpublished) material.
- The Koninklijke Bibliotheek National Library of the Netherlands (KB) have WAV as the top audio format listed in their 50 most prevalent formats in their e-Depot, ranking narrowly above MP3 in terms of file numbers [22].
- At the Phonogrammarchiv (Institute for Audiovisual Research and Documentation) in Austria, WAV is again viewed as a *de facto* standard and, therefore, recommended for the digitisation of at risk audio recordings [23].
- Binghamton University Libraries offers "full support" for the WAV format, due to its ability to store data in an uncompressed format and its wide use suggesting it will have long-term community

support [24], an approach supported by many other US universities, including Boston University Libraries [25] and the University of Michigan [26].

- The BBC has a technical specification for audio data files used for radio programme material which approves the use of WAV at a similar specification (Linear PCM, 48 kHz, 16 Bit) to the British Library's, however it does also endorse the use of the FLAC format for when files are especially large [27] [28]. For archiving also, it has endorsed the use of WAV, for example, on projects such as the conversion of 5800 mini-discs [28].

2.3 Software Support

2.3.1 Rendering Software Support

An overall impression of software support for rendering the format with reference to: typical desktop software; and current support on British Library reading room PCs

A wide range of proprietary and open-source applications can access and play WAV files [10] [29], due largely to its simple structure; this includes Windows Media Player [30], Apple iTunes [31], the VideoLAN VLC media player [32], and the Clementine music player [33]. Playback software which comes preloaded with most operating systems (not just Windows OS) can typically play WAV files [29]. Other non-proprietary open source media players which can play WAV include Real Player [34], Foobar2000 [35] and MPlayer [36] [37] [38].

The previously mentioned BWF variants do not require a special player for playback though some may not be able to access the metadata in the additional chunk [18]. The DPC Technical Watch Report on *Preserving moving pictures and sound*, in supporting BWF, states that whilst the BWF wrapper itself may eventually become obsolete [16], the only significant problem with the format is the failure of some standard audio applications to correctly handle the embedded metadata. This is based on the findings of Association for Recorded Sound Collections Technical Committee report [39].

Issues

Most WAV players demonstrate an ability to play badly formed files. The evidence suggests that though the reader may not fully understand all the metadata chunks, this is discarded by the application and it is still able to handle the file [38].

Previous to the implementation of RF64 at the British Library, there were initial concerns regarding interoperability, but no problems have yet been encountered and there is no evidence of any amongst the archival community.

2.3.2 Preservation Software Support

An impression of the availability and effectiveness of software for managing and preserving instances of the file format

Format identification

Successful identification is supported by a wide range of preservation software including JHOVE, Apache Tika and DROID. JHOVE provides a WAVE-hul module which recognizes and validates the WAV format [40]; Apache Tika can detect several common audio formats including WAV [41]; while DROID uses internal signatures to identify and report the specific file format and version of digital files generated from information in the PRONOM technical registry that includes WAV [42]. FIDO (Format Identification for Digital Objects) [43] also makes use of PRONOM and so is also able to detect WAV files. Xena is another open source tool which is able to detect WAV [44].

It should be noted that BWF files still use the same .wav file extension as traditional WAV files, so the extension alone will never be sufficient for identification of the file in question.

Validation and Detecting Preservation Risks

JHOVE provides validation support to WAV files through the use of its WAVE-hul module [40] though available evidence suggests that it doesn't check the audio data itself (it only checks the structure of the file and metadata), so if the audio was corrupted this wouldn't be reported [45].

Conformance Checking

Open source software tools such as MediaInfo provides a display of technical information and metadata about WAV files including format, profile, duration, overall bit rate and writing application and library [46]. There are also specialist open source tools available such as XcorrSound which allow you to compare

waveforms, enabling the analysis of overlap between two WAV files, or the detection of one waveform within another [47].

Whilst WAV can be lossless, this doesn't mean that the original source of the audio might not be lossy; tools such as Audiochecker [48] allow you to verify whether the encoding is truly lossless (e.g., migrated from an MP3 file for example). The use of spectrogram software such as Spek would also allow you to perform the same check through an analysis and interpretation of the spectrogram [49].

Metadata Extraction

As a derivative of RIFF, WAV files can be tagged with metadata in the INFO chunk. In addition, WAV files can embed any kind of metadata, including but not limited to Extensible Metadata Platform (XMP) data or ID3 tags in extra chunks. Applications may not handle this extra information or may expect to see it in a particular place [1]. WAV audio files can hold several metadata types (for example, information about the file such as Title, Artist or Genre). As the format has changed over time, several other types have been introduced [38] such as the four metadata chunks established for BWF [5], AES46 for network and file transfer [50], axml for storing and transferring metadata as XML [51], iXML to facilitate transfer of production metadata [52] and Adobe's XMP specification for project or production information [53]).

There are many free WAV and editing tools that will open the audio file header and display a form into which you can fill in the information [38]. Alternatively, there are also music editing and processing software such as Pro Tools [54], which also prompts you to add metadata to the file when you save the file as a WAV [55] [56].

There are a number of tools available for the extraction of metadata from WAV including: the NLNZ Metadata Extraction tool [57], Exiftool [58] and Apache Tika [41].

BWF MetaEdit was developed by the US Federal Agencies Digitization Guidelines Initiative (FADGI) with the support of AudioVisual Preservation Solutions [59]. BWF MetaEdit permits embedding, validating, and exporting of metadata in Broadcast WAVE Format (BWF) files. Guidelines are also available on embedding metadata from FADGI [60].

Migration

There are several tools [61] available to convert files (including the metadata) to WAV such as SoX [62] and the aforementioned Xena software [44]. However, migration results will only be as successful as the input dat, e.g. a lossy file is not going to become lossless simply through migration. Ffmpeg is a free software project which has several components as part of its toolkit including ffprobe which can record, convert and stream audio and video [63].

For migration from WAV to other file types, there is a lot of free software available [64] including EZ Audio CD Converter [65] or AudioFormat.com [66]; iTunes has MP3 conversion built in to its functionality.

2.4 Documentation and Guidance

An indication of the availability of practical documentation or guidance with specific reference to the facilitation of any recommended actions

There is no official standard published for WAV itself. However, the Multimedia Programming Interface and Data Specifications 1.0 issued jointly in August 1991 by IBM and Microsoft provides a specification for RIFF as a whole; it also contains an overview of the WAV specification [67].

New RIFF file forms and chunks were later defined in a revised document from Microsoft, New Multimedia Data Types and Data Techniques, published in 1994 [68]. An overview of the WAV format is also available from McGill University's Telecommunication and Signal Processing Laboratory [69].

The EBU published a version 2.0 specification for BWF in 2011 [8] and also published a technical specification for RF64 in 2009 [9].

2.5 Complexity

An impression of the complexity of the format with respect to the impact this is likely to have on the British Library managing or working with content in this format. What level of expertise in the format is required to have confidence in management and preservation?

It has been suggested that WAV is "arguably the most basic of sound formats available" [70] due to its simple structure and stable history. Despite the creation of the various extensions since WAV was introduced in 1991, the Remo Software Glossary states that it remains an "uncomplicated format to work

with and is recognised as one of the simplest digital audio formats" [10]. Files are playable on almost any media player currently available [29]; however, as WAV is "rather loosely defined, Dan Waters comments that there are a lot of WAV files "that theoretically should not work, but somehow do" [70]. There are also some "inconsistencies in the WAV format: for example, 8-bit data is unsigned[1] while 16-bit data is signed, and many chunks duplicate information found in other chunks" [1].

2.6 Embedded or Attached Content

The potential for embedding or attaching files of similar or different formats, and the likely implications of this

Metadata can be embedded into WAV files; guidelines on this are available from the Federal Agencies Audio-Visual Working Groups' specifications published in 2009 and revised in 2012 [60]. It is recommended that metadata is embedded in the <bext> chunk when using BWF [71]. There may be parts of the metadata chunk that WAV players and readers do not understand, in which case they tend to be discarded by the application [38].

2.7 External Dependencies

An indication of the possibility of content external to an instance of the file format that is complimentary or even essential to the intellectual content of the instance

None known.

2.8 Legal Issues

Legal impediments to the use, management or preservation of instances of the file format

WAV is a proprietary format developed by Microsoft and IBM as part of the Resource Interchange File Format (RIFF) for Windows 3.1, with documentation freely available. BWF and RF64 are both open standards developed by the European Broadcasting Union [5]. No licensing is required [18] and there are no patents which affect its usage or any of the associated encoding standards such as LPCM.

2.9 Technical Protection Mechanisms

Encryption, Digital Rights Management and any other technical mechanisms that might restrict usage, management or preservation of instances of the file format

DRM (Digital Rights Management) on digital audio files is less prevalent than it once was but may still be an issue with older supplied items. File properties details will generally indicate the presence of DRM [72] [73].

Software is available to detect DRM in WAV (normally as a single feature of an overall software package). This includes Danuisoft MP3 WAV Converter [74], MP3 WAV Converter [75] or Aimersoft DRM Media Converter [76].

2.10 Other Preservation Risks

Other evidence based preservation risks, noting that many known preservation risks are format specific and do not easily fit under any of the sustainability factors above

None known.

2.11 Preservation Risk Summary

A summary of preservation risks and recommended actions (where possible).

The evidence discussed above finds very few risks associated with the format and continues to demonstrate widespread adoption for archival and broadcasting purposes. Many of the issues relate to metadata capabilities rather than the format itself, and despite potential competition from the FLAC (Free Lossless Audio Codec) format, use of WAV still shows no sign of decline and the format remains compliant with almost any current media player [29].

The main issues include:

[1] Signed and unsigned refer to the scales used to represent amplitude values. A signed number can be either positive or negative whilst signed are always positive [78].

- Large file sizes
  - WAV files are very large, alternative lossless formats such as FLAC are smaller
- File size limitations
  - WAV has a file size limit of 4GB; BWF maintains this restriction
  - RF64 is a variant which overcomes this limitation
- Rendering
  - A wide range of proprietary and open-source applications can access and play WAV files
  - BWF variants do not require a special player for playback though some may not be able to access the metadata in the additional chunk
  - Failure of some standard audio applications to correctly handle the embedded metadata
  - Most WAV players demonstrate an ability to play badly formed files
  - Initial concerns regarding interoperability regarding RF64, no evidence of any amongst the archival community
- File extensions
  - BWF files have the same extension .wav as traditional WAV files, so the extension alone will never be sufficient for identification
- Data validation
  - JHOVE doesn't check the audio data itself (it only checks the structure of the file and metadata), so if the audio was corrupted this wouldn't be reported
- Misidentification of lossless format
  - WAVE files may contain lossy data if migrated from a lossy format
- Lack of standards
  - There is no official standard published purely about WAV
  - WAV is loosely defined in any documentation which does exist
- Digital rights management
  - DRM may be present in older files.

3. Recommendations for Action

Recommended actions in usage and handling of the format. Recommend actions in the support or development of software applications that provide, or have the potential to provide, significant risk mitigation for the format. Note that these recommendations do not take into account other requirements such as those driven by specific British Library collections, or non-preservation issues such as resourcing.

The prevalence of WAV amongst the broadcasting and archival community and the format's relative simplicity means there we are able to identify few preservation risks. The biggest current risk to it would appear to be a shift to a higher resolution format [77], although there appears to be no appetite for this at the present time. We have a small number of recommendations to make regarding the current and future use of WAV.

Handling Recommendations

- Where there is a choice of audio file formats options for the submission of content, WAV should be selected whenever available, or RF64 when appropriate
- Wherever possible and appropriate to the workflow, submitted content should be validated using JHOVE
- Wherever possible, metadata creation should be semi-automated

Software Recommendations

- An evaluation of the role JHOVE can play in the identification and validation of possible corrupt file content

Monitoring Recommendations

The preservation risks and general acceptance of the WAV format for archival sound are unlikely to change in the short term; therefore, there will be no need for a regular review of this assessment. However, there does need to be an awareness of new standards and developments in the field of digital audio. Specific recommendations include:

- An awareness of new specifications or technical documentation relating to WAV or RF64
- A greater awareness of future developments in the field of digital audio
- The monitoring of other formats (e.g. FLAC) as potential alternative formats for the preservation of digital audio
- The creation of knowledge bases of example files and evidence, e.g. based on case studies

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